HEART.

A JOURNAL FOR THE STUDY OF THE CIRCULATION.

EDITED BY

THOMAS LEWIS, M.D.,

AIDED IN THE SELECTION OF PAPERS BY

Prof. A. R. CUSHNY (London).
Dr. LEONARD HILL (London).
Sir J. MACKENZIE (London).
Prof. G. N. STEWART (Cleveland).

15 1676
16/8/19

WITH THE COLLABORATION OF

VOL. VI,
1915-1917.

Publishers:
SHAW & SONS, 7, 8 & 9, FETTER LANE, FLEETS TREET, LONDON, E.C.4.

1917

CONTENTS OF VOL. VI.

No. 1 (*Issued April* 30, 1915).

PAGE

WALTER HOLBROOK GASKELL, M.D., F.R.S., FELLOW OF TRINITY HALL AND UNIVERSITY LECTURER IN PHYSIOLOGY, CAMBRIDGE 1

PAROXYSMAL HEART-BLOCK WITH PAROXYSMAL AURICULAR FIBRILLATION. By K. Douglas Wilkinson and H. G. Butterfield 3

AURICULAR FIBRILLATION FOLLOWING COMPLETE HEART-BLOCK IN DIPHTHERIA. By John Parkinson (*from the Cardiac Department of the London Hospital*) 13

REPORT OF A CASE SHOWING PREMATURE BEATS ARISING IN THE JUNCTIONAL TISSUES. By F. N. Wilson (*Department of Internal Medicine, University of Michigan*) 17

TACHYCARDIA OF AURICULAR ORIGIN AND FLUTTER WITH PHASIC VARIATION IN AURICULAR RATE AND IN CONDUCTION. By John Parkinson and H. H. Mathias (*from the Cardiac Department of the London Hospital*) 27

SUPPLEMENTARY NOTE ON A CASE OF HEART-BLOCK. By T. Wardrop Griffith. WITH AN EXAMINATION OF THE AURICULO-VENTRICULAR JUNCTIONAL TISSUE. By A. M. Kennedy .. 37

OBSERVATIONS ON THE THIRD HEART SOUND. By E. W. Bridgman (*The Johns Hopkins Hospital*) 41

CONTENTS,

PAGE

DIRECT PULSATION RECORDS: A NEW PHOTOGRAPHIC METHOD. By John Parkinson (*from the Cardiac Department of the London Hospital*) 57

A CASE OF VENTRICULAR FIBRILLATION. By R. H. Halsey (*New York*) 67

OBSERVATION UPON CHEYNE-STOKES BREATHING. By F. T. Fulton (*Providence*) 77

A CASE EXHIBITING A SLOW ATRIO-VENTRICULAR RHYTHM. By E. E. Laslett (*Hull*) 81

THE PHYLOGENETIC DEVELOPMENT OF THE BULBAR AND VENTRICULAR SEPTA OF THE HEART. By Jane I. Robertson (*from the Victoria Infirmary, Glasgow*) 87

CARDIAC MALFORMATIONS IN WHICH THE GREAT EFFERENT VESSELS ARISE FROM THE RIGHT VENTRICLE. By Jane I. Robertson (*from the Victoria Infirmary, Glasgow*) 99

No. 2 (*Issued October* 18, 1915).

ON THE VARIABILITY OF THE SIZE OF THE PULSE IN CASES OF AURICULAR FIBRILLATION. By W. Einthoven and A. J. Korteweg (*from the Physiological Laboratory, Leyden*) .. 107

FURTHER GRAPHIC RESEARCHES ON THE ACOUSTIC PHENOMENA OF THE HEART IN NORMAL AND PATHOLOGICAL CONDITIONS. By P. J. T. A. Battaerd (*from the Physiological Laboratory, University of Leyden*) 121

THE EFFECT OF REMOVAL OF LARGE PORTIONS OF THE TOTAL RENAL SUBSTANCE ON THE HEART. By F. J. F. Barrington (*from the Graham Research Laboratories, University College Hospital Medical School*) 163

EFFECTS OF UNILATERAL DEPRESSION OF VENTRICULAR CONDUCTIVITY. By A. L. Prince and L. A. Geraci (*from the Laboratory of Physiology, Yale School of Medicine*) 167

CONTENTS.

No. 3 (*Issued January* 24, 1917).

PAGE

VOLUNTARY ACCELERATION OF THE RATE OF THE HEART BEAT. By John Favill (*Chicago*) and Paul Dudley White (*Massachusetts General Hospital, Boston*) 175

ELECTROCARDIOGRAPHIC STUDIES IN NORMAL INFANTS AND CHILDREN. By Edward B. Krumbhaar and Horace H. Jenks (*from the Department of Medicine, University of Pennsylvania and The Pepper Laboratory of Clinical Medicine*) 189

TWO CASES OF BRADYCARDIA IN HORSES. ADAM STOKE'S DISEASE. SINUS - BRADYCARDIA. By O. Bang, G. Petersen and Otto V. C. E. Petersen (*from the Veterinary College and Rigshospital, Copenhagen*) 199

THE HEART OF THE SPERM WHALE WITH ESPECIAL REFERENCE TO THE *A-V* CONDUCTION SYSTEM. By Paul D. White and William J. Kerr (*from the Medical Service of the Massachusetts General Hospital*) 207

OBSERVATIONS UPON HYPERTROPHY. By Thomas F. Cotton (*Montreal General Hospital*) 217

OBSERVATIONS UPON DERMATOGRAPHISM WITH SPECIAL REFERENCE TO THE CONTRACTILE POWER OF CAPILLARIES. By Thomas F. Cotton, J. G. Slade and Thomas Lewis 227

No. 4 (*Issued May* 20, 1917).

INTIMAL KELOID-LIKE THICKENING OF THE FEMORAL AND EXTERNAL ILIAC ARTERY AND ITS RELATION TO ARTERIOSCLEROSIS. By Dr. Med. Max des Ligneris (*from the Pathological Institute, Basle. Director, Prof. Dr. E. Hedinger*) 249

AFTER EFFECTS OF EXERCISE ON PULSE RATE AND SYSTOLIC BLOOD PRESSURE IN CASES OF "IRRITABLE HEART." By T. F. Cotton, D. L. Rapport and Thomas Lewis (*from the Military Hospital, Hampstead*) 269

CONTENTS.

	Page
The Pulse Rate after a Simple Test Exercise in Cases of "Irritable Heart." By J. C. Meakins and E. B. Gunson (*from the Military Hospital, Hampstead*)	285
Observation upon Atropine. By T. F. Cotton, D. L. Rapport and Thomas Lewis (*from the Military Hospital, Hampstead*)	293
Observations upon Pilocarpine Nitrate. By T. F. Cotton, J. G. Slade and Thomas Lewis (*from the Military Hospital, Hampstead*)	299
Observations upon Amyl Nitrite. By T. F. Cotton, J. G. Slade and Thomas Lewis (*from the Military Hospital, Hampstead*)	311
The Pulse Rate on Standing and on Slight Exertion in Healthy Men and in Cases of "Soldier's Heart." By John Parkinson (*from the Military Hospital, Hampstead*)	317
Digitalis in Soldiers with Cardiac Symptoms and a Frequent Pulse. By John Parkinson (*from the Military Hospital, Hampstead*)	321
The *P-R* Interval Before and After Exercise in Cases of "Soldier's Heart." By John Parkinson and A. N. Drury (*from the Military Hospital, Hampstead*)	337
The Occurrence of Hyperalgesia in the "Irritable Heart of Soldiers." By J. C. Meakins and E. B. Gunson (*from the Military Hospital, Hampstead*)	343

LIST OF AUTHORS.

PAGE

BANG, O., PETERSEN, G., AND PETERSEN, OTTO V. C. E. "Two Cases of Bradycardia in Horses. Adam Stoke's Disease. Sinus-Bradycardia" 199

BARRINGTON, F. J. F. "The Effect of Removal of Large Portions of the Total Renal Substance on the Heart" 163

BATTAERD, P. J. T. A. "Further Graphic Researches on the Acoustic Phenomena of the Heart in Normal and Pathological Conditions" 121

BRIDGMAN, E. W. "Observations on the Third Heart Sound" 41

BUTTERFIELD, H. G., AND WILKINSON, K. DOUGLAS. "Paroxysmal Heart-Block with Paroxysmal Auricular Fibrillation" 3

COTTON, THOMAS F. "Observations upon Hypertrophy" 217

COTTON, T. F., RAPPORT, D. L., AND LEWIS, THOMAS. "After Effects of Exercise on Pulse Rate and Systolic Blood Pressure in Cases of "Irritable Heart" 269

"Observation upon Atropine" 293

COTTON, T. F., SLADE, J. G., AND LEWIS, THOMAS. "Observations upon Dermatographism with Special Reference to the Contractile Power of Capillaries 227

"Observations upon Pilocarpine Nitrate" 299

"Observations upon Amyl Nitrite" 311

DES LIGNERIS, MAX. "Intimal Keloid-like Thickening of the Femoral and External Iliac Artery and its Relation to Arteriosclerosis" 249

DRURY, A. N., AND PARKINSON, JOHN. "The *P-R* Interval Before and After Exercise in Cases of 'Soldier's Heart'" 337

EINTHOVEN, W., AND KORTEWEG, A. J. "On the Variability of the Size of the Pulse in Cases of Auricular Fibrillation" 107

FAVILL, JOHN, AND WHITE, PAUL DUDLEY. "Voluntary Acceleration of the Rate of the Heart Beat" 175

FULTON, F. T. "Observation upon Cheyne-Stokes Breathing" 77

GERACI, L. A., AND PRINCE, A. L. "Effects of Unilateral Depression of Ventricular Conductivity" 167

GRIFFITH, T. WARDROP, AND KENNEDY, A. M. "Supplementary Note on a Case of Heart-Block. With an Examination of the Auriculo-Ventricular Junctional Tissue" 37

GUNSON, E. B., AND MEAKINS, J. C. "The Pulse Rate after a Simple Test Exercise in Cases of 'Irritable Heart'" 285

"The Occurrence of Hyperalgesia in the 'Irritable Heart of Soldiers'" 343

HALSEY, R. H. "A Case of Ventricular Fibrillation" 67

JENKS, HORACE H., AND KRUMBHAAR, EDWARD B. "Electrocardiographic Studies in Normal Infants and Children" 189

KENNEDY, A. M., AND GRIFFITH, T. WARDROP. "Supplementary Note on a Case of Heart-Block. With an Examination of the Auriculo-Ventricular Junctional Tissue" 37

KERR, WILLIAM J., AND WHITE, PAUL D. "The Heart of the Sperm Whale with Especial Reference to the *A-V* Conduction System" 207

KORTEWEG, A. J., AND EINTHOVEN, W. "On the Variability of the Size of the Pulse in Cases of Auricular Fibrillation" 107

LIST OF AUTHORS.

PAGE

KRUMBHAAR, EDWARD B., AND JENKS, HORACE H. "Electrocardiographic Studies in Normal Infants and Children" 189

LASLETT, E. E. "A Case Exhibiting a Slow Atrio-Ventricular Rhythm" 81

LEWIS, THOMAS, COTTON, T. F., AND RAPPORT, D. L. "After Effects of Exercise on Pulse Rate and Systolic Blood Pressure in Cases of "Irritable Heart" 269

"Observation upon Atropine" 293

LEWIS, THOMAS, COTTON, T. F., AND SLADE, J. G. "Observations upon Dermatographism with Special Reference to the Contractile Power of Capillaries" 227

"Observations upon Pilocarpine Nitrate" 299

"Observations upon Amyl Nitrite" 311

MATHIAS, H. H., AND PARKINSON, JOHN. "Tachycardia of Auricular Origin and Flutter with Phasic Variation in Auricular Rate and in Conduction" 27

MEAKINS, J. C., AND GUNSON, E. B. "The Pulse Rate after a Simple Test Exercise in Cases of 'Irritable Heart'" 285

"The Occurrence of Hyperalgesia in the 'Irritable Heart of Soldiers'" 343

PARKINSON, JOHN. "Auricular Fibrillation following Complete Heart-Block in Diphtheria" 13

"Direct Pulsation Records: A New Photographic Method" 57

"The Pulse Rate on Standing and on Slight Exertion in Healthy Men and in Cases of 'Soldier's Heart'" 317

"Digitalis in Soldiers with Cardiac Symptoms and a Frequent Pulse" 321

PARKINSON, JOHN, AND DRURY, A. N. "The *P-R* Interval Before and After Exercise in Cases of 'Soldier's Heart'" 337

PARKINSON, JOHN, AND MATHIAS, H. H. "Tachycardia of Auricular Origin and Flutter with Phasic Variation in Auricular Rate and in Conduction" 27

PETERSEN, G., BANG, O., AND PETERSEN, OTTO V. C. E. "Two Cases of Bradycardia in Horses. Adam Stoke's Disease. Sinus-Bradycardia" 199

PETERSEN, OTTO V. C. E., BANG, O., AND PETERSEN, G. "Two Cases of Bradycardia in Horses. Adam Stoke's Disease. Sinus-Bradycardia" 199

PRINCE, A. L., AND GERACI, L. A. "Effects of Unilateral Depression of Ventricular Conductivity 167

RAPPORT, D. L., COTTON, T. F., AND LEWIS, THOMAS. "After Effects of Exercise on Pulse Rate and Systolic Blood Pressure in Cases of "Irritable Heart" 269

"Observations upon Atropine" 293

ROBERTSON, JANE I. "The Phylogenetic Development of the Bulbar and Ventricular Septa of the Heart" 87

"Cardiac Malformations in which the Great Efferent Vessels arise from the Right Ventricle" 99

SLADE, J. G., COTTON, T. F., AND LEWIS, THOMAS. "Observations upon Dermatographism with Special Reference to the Contractile Power of Capillaries" 227

"Observations upon Pilocarpine Nitrate" 299

"Observations upon Amyl Nitrite" 311

WHITE, PAUL DUDLEY AND FAVILL, JOHN. "Voluntary Acceleration of the Rate of the Heart Beat" 175

WHITE, PAUL D., AND KERR, WILLIAM J. "The Heart of the Sperm Whale with Especial Reference to the *A-V* Conduction System .." 207

WILKINSON, K. DOUGLAS, AND BUTTERFIELD, H. G. "Paroxysmal Heart-Block with Paroxysmal Auricular Fibrillation" 3

WILSON, F. N. "Report of a Case showing Premature Beats arising in the Junctional Tissues" 17

Yrs sincerely
W. H. Gaskell

Elliott & Fry.

WALTER HOLBROOK GASKELL, M.D., F.R.S.

Fellow of Trinity Hall and University Lecturer in Physiology, Cambridge.

PHYSIOLOGICAL Science has suffered a great loss in the death of Dr. Walter Holbrook Gaskell, which took place on September the 7th, after an illness which was, happily, very brief. Dr. Gaskell was in his 66th year.

Two important discoveries, each of a fundamental nature, are due to him. Each of these, also, is of especial interest to those concerned with problems of the heart and circulation.

The first is that of the myogenic nature of the heart beat, to use the name generally applied to this doctrine; the second is that of the nature of the sympathetic nervous system, with its control of the peripheral blood vessels.

Gaskell's contributions to cardiac physiology are mainly contained in papers published in the *Philosophical Transactions*, of 1882, and in the *Journal of Physiology*, of 1883. His observations arose from those of Romanes upon the contractile umbrella of jelly-fishes. By his work on the heart of the frog and tortoise, he showed that the heart beat arises in the muscular tissue itself and that the origin is in discrete rather than in continuous impulses. He unravelled, by clear and ingenious experiments, the underlying causes which guide the sequence of the contractions of the separate chambers of the heart, holding that transmission of the excitatory process is affected through muscular continuity and not by nervous channels. The various hindrances to conduction, leading to the phenomenon which he termed heart-block and with which clinicians are so familiar at the present time, were described by him in detail. He was the first to recognise in heart muscle the several attributes which he termed "rhythmicity, excitability, contractility, conductivity and tonicity," and to point out the way in which these properties are affected by the vagus and sympathetic nerve supply of the heart. His was the broad, morphological view, which recognized that specified areas of the musculature are specially endowed with these properties; maintaining that those regions which have been least differentiated in development are the most rhythmic but possess the slowest power of conduction.

His work upon the innervation of the cold-blooded heart has become classical. The wealth of detail and accurate observations contained in his papers render them a storehouse frequently visited by students of the present day.

A point of great interest in connection with the mode of action of the inhibitory nerves was brought out by Gaskell when he showed that stimulation of the vagus causes an electrical change in heart muscle of opposite sign to that associated with contraction, while the sympathetic nerve produces a change opposite to that of the vagus. Although these observations had been disputed, recent experiments have confirmed their accuracy.

Gaskell's work upon the physiology of the heart stands forth as the basis of the present day conceptions of disordered mechanism in the human being. Lying dormant for many years, the seed which he sowed has sprung to life and its fruits have been gathered a hundredfold.

The second great piece of work which he did was to show that the efferent nerve fibres forming the sympathetic nervous system all leave the spinal cord over a limited region comprised between the upper thoracic and upper lumbar segments and that the whole of the sympathetic innervation of the body is supplied from this area. The evidence for this is contained in a paper entitled "On the Structure, Distribution and Function of the Nerves which innervate the visceral and vascular Systems," published in the *Journal of Physiology* in 1885. The only phrase applicable to the description of this paper is that it is, in the literal meaning of the words, "epoch making." It has served as the foundation of all subsequent investigations on the relation of the sympathetic system, both in structure and functions, to the somatic system. It contains, also, valuable discoveries with regard to the other visceral nerves and to the cranial nerves. The latter served also as the subject of another paper. It should be mentioned, also, that the characteristic property of the sympathetic fibres of being interrupted by a synapse with a ganglion cell, before reaching their destination, was clearly pointed out, together with the fact of the loss of the medullary sheath at this synapse.

It is a matter of satisfaction to know that Gaskell had just completed the manuscript of a monograph containing his latest work on the visceral nervous system, which will shortly be published.

The investigation of the cranial nerves led to the well known theory of the origin of vertebrates from invertebrate ancestors, which is associated with Gaskell's name. A great part of the later years of his life was devoted to a minute and elaborate consideration of the various evidences to be obtained on this question. A very powerful body of facts was brought forward in support of the theory and published in his book, "The Origin of Vertebrates," in 1908. Although the theory has not, as yet, met with general acceptance on the part of morphologists, there are not a few who regard it with favour, and it appeals especially to physiologists on account of the main thesis, which is that the evolution of the nervous system has been the dominant factor, other systems having to adapt themselves to it. The words used by Gaskell are worth recording :—

"The law of progress is this :—The race is not to the swift, nor to the strong, but to the wise."

The research which Gaskell, in conjunction with Dr. L. E. Shore, undertook for the Hyderabad Commission on chloroform should be mentioned. The most important fact established was that chloroform produces a depressant effect on the heart in much smaller doses than those necessary to paralyse the vaso-motor centres or the blood vessels themselves.

This is not the place to speak at length of Gaskell's personal character. It is sufficient to say one thing, that he was beloved by all who knew him.

W. M. B.

PAROXYSMAL HEART-BLOCK WITH PAROXYSMAL AURICULAR FIBRILLATION.

By K. DOUGLAS WILKINSON and H. G. BUTTERFIELD.

The patient, aged 69, was admitted to hospital in November, 1912, complaining of blood-spitting and pains in the chest of seven months' duration. He said that until the age of 67 he had enjoyed very good health, but for two years he had suffered from bronchitis and "giddy turns." The family history was good; he had taken very little alcohol and was a non-smoker. He had attended his work (that of a brass founder) until shortly after the blood-spitting began, but then, owing to frequent attacks, shortness of breath and general weakness he had to give it up. The pain first began in the inter-scapular region but later moved to the front of the chest. It had been very severe but at the time of admission was slight. His weight had diminished considerably since the commencement of the illness.

Condition on admission. The patient was a thin and pale old man, easily rendered dyspnœic, even by the exertion of speaking. His cough was frequent; with a muco-purulent sputum containing streaks of bright blood. The chest was large and symmetrical but movement of both sides was impaired, especially of the left. All over this side the percussion note was poor and at the base there was definite consolidation. The heart was obscured by the lungs and no impulse could be felt. The heart sounds were feeble but clear, except in the aortic area where a short rough systolic murmur was heard. There was nothing to direct any special attention to the heart until November the 10th. On the morning of that day, after his chest had been examined, he sat up in bed, put on his shirt and lay down again. It was then noticed that no pulse could be felt at the wrist although a few minutes previously it had been full (90 per minute). On looking at his face he was seen to be more pallid than usual; he then closed his eyes, lost consciousness, and had a typical Stokes-Adams attack. In this he made some convulsive movements of the legs and arms and his face twitched slightly. The convulsions lasted about ten seconds before the pulse returned and the duration of the whole attack was, perhaps, half a minute. When the pulse did return it was very slow, and after some ten beats stopped again, when another attack commenced. After these attacks the pulse remained at a rate of about thirty-six per minute for twenty minutes and fortunately a tracing was obtained showing the return to the normal (Fig. 1). Thereafter the pulse remained normal in frequency and rhythm until the following day. With regard to this attack the patient stated that he had never suffered from a similar condition, but thought that he had fallen asleep. He was not in the least alarmed and said that the "giddy turns" were not at all like this attack.

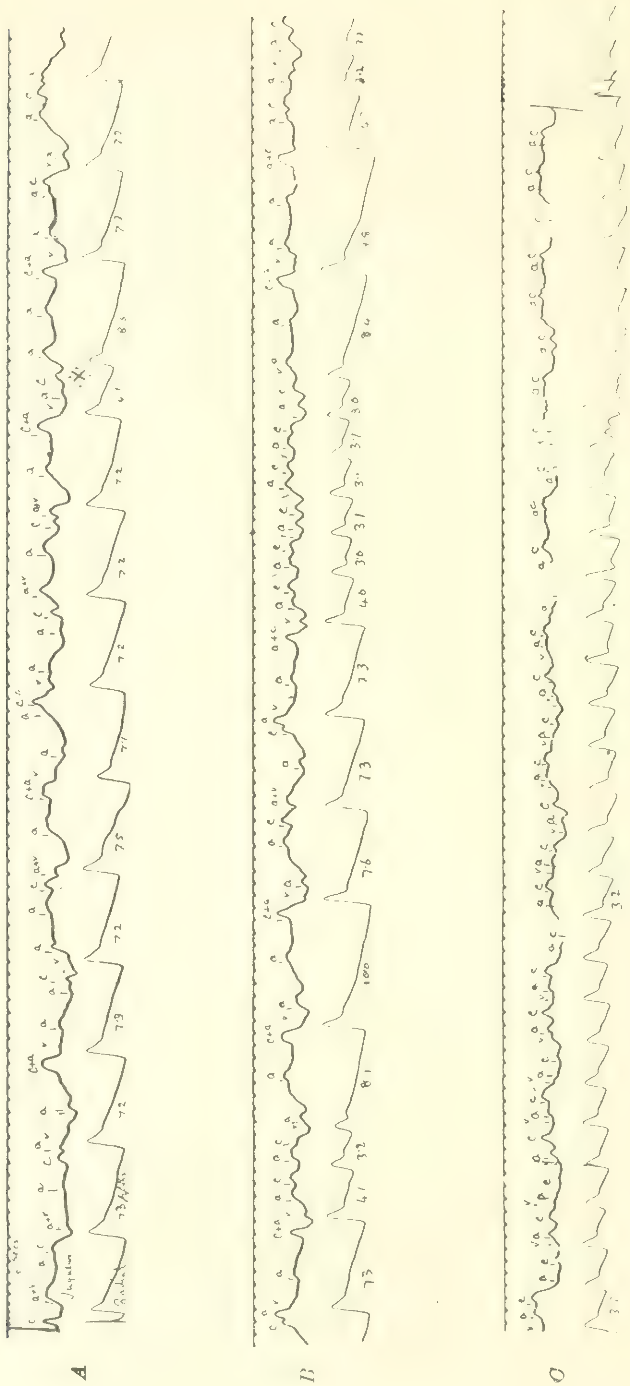


Fig. 1.

On the following morning he was again examined, and after putting on his shirt had two more attacks similar in every respect to those described. On this occasion the pulse remained slow for about four hours after the attacks. From November the 10th to February the 17th the pulse was taken every hour in order to note any variation in rate and rhythm. Tracings taken on several occasions showed that the intermissions were due to dropped ventricular beats occasioned by impairment of conduction from auricle to ventricle and that the irregularity was due to auricular fibrillation.

The following is a summary of the dates and duration of the variations noted as "intermittent" or "irregular." It is probable that there were abnormal periods of short duration which were not noticed, but these cannot have been frequent, as the patient was distinctly uncomfortable during the paroxysms of auricular fibrillation. When the ventricular contraction failed three or four beats were dropped in each minute and no heart sounds could be heard corresponding in time to the dropped beats. On all these occasions (with one exception) the patient was seen by one of us (K. D. W.), and on eight occasions tracings were obtained.

Date.	Duration of Attack.	Pulse rate.	Condition present.
Nov. 10th	30 minutes	36	Complete heart-block
,, 11th	4 hours	36	Complete heart-block
,, 12th	2½ hours	112	Auricular fibrillation
,, 16th	1 hour	80	Dropped beats
,, 18th	1 hour	74	Dropped beats
,, 18th	4 hours	80-116	Dropped beats and later auricular fibrillation
,, 22nd	30 minutes	82	Dropped beats
,, 28th	1 hour	104	Auricular fibrillation
Dec. 5th	1 hour	84	Dropped beats
,, 27th	30 minutes	84	Dropped beats
Jan. 18th	1 hour	100	Auricular fibrillation
Feb. 15th	2 hours	100	Auricular fibrillation (Not seen on this occasion)

The patient's general condition became worse and worse, and he died on March the 11th, 1913.

Tracings. Fig. 1 is divided in three parts (*A*, *B* and *C*). They form a continuous polygraphic tracing and are read from left to right. Part *A* shows a condition of complete heart-block, there being no relationship between the auricular and ventricular beats. There is slight variation in the length of the ventricular cycles. At a point marked by an asterisk this rhythm is interrupted by an isolated ventricular response to the auricle: the pause following this beat is prolonged, being 8·5-fifths of a second in length. Part *B* begins with a condition of complete heart-block, but early in the curve there are two responses to the auricle: there follow two longer beats before the ideo-ventricular rhythm regains its former frequency. Three beats later there is a series of six rapid beats, obviously responses to

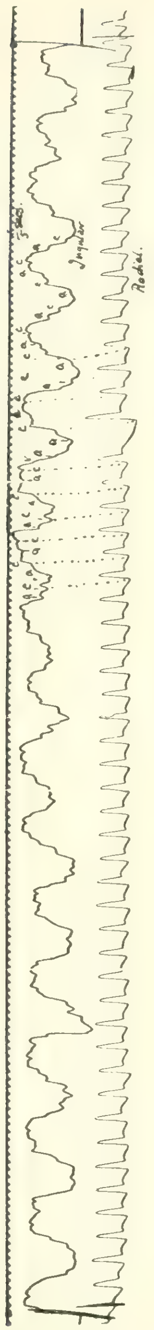

Jugular
Radial

Fig. 2.


5 secs.
Jugular
Radial
3·6 d.f.p.s. 3 4 3 3·7 3·3 2·5 3·2 4·5 2·3 2·2 2 2·6

Fig. 3.

the auricle; these are followed by two long beats of ventricular origin and then the normal rhythm (each ventricular beat being a response to the auricle) is resumed. Part *C* shows the continuation of the normal rhythm.

The tracing thus shows the transition from a condition of complete heart-block to the normal rhythm. A curious and possibly unique feature of this tracing is the fact that whenever the ventricle responds to the auricle the "*a-c*" interval is a constant, although the heart during this period showed variations in conduction from complete heart-block to the normal rhythm. The "*a-c*" interval is only slightly longer than the normal, being in fact rather more than one-fifth of a second in duration. The prolonged ventricular cycles after responses to the auricle appear to lend support to the suggestion that the ventricular pacemaker is readily fatigued by rapid ventricular beats. Cushny (this *Journal, Vol. III*) obtained these prolonged cycles in experimental heart-block. He found that a series of induced beats in an isolated ventricle led to a slowing of the ideo-ventricular rhythm.

Fig. 3 shows a regular heart beat with a normal sequence of chambers. There is one dropped beat in the radial curve followed by some alternation. The pause might be due to an extra-systole of the ventricle so weak that it failed to affect the pulse, but there is no evidence of such an event in the venous curve, while the pause is too short to lend support to this view. The fact that no heart sounds could be heard corresponding to the pause makes it more probable that the ventricle has for one beat failed to respond to the auricle. Fig. 4 shows auricular fibrillation.

Autopsy.

The heart was definitely enlarged and weighed sixteen ounces. There was no excess of epicardial fat on the surface, and the superficial vessels were very prominent. The *pericardium* was thickened, and at one point was roughened and shaggy. The whole of the *right side* was hypertrophied and dilated. The interior of the chambers was normal and there were no valvular lesions. There was a small patch of atheroma on the wall of the pulmonary artery about an inch away from the valves. The *left auricle* was greatly dilated. The interior was normal and showed nothing more than a blood-stained endocardium. The *left ventricle* was hypertrophied and dilated. The mitral valve showed some old thickening at the edges of the cusps, but there were no signs of recent mischief, and the remainder of the endocardium was normal. The *aortic valves* were normal except that the corpus Arantii of the left cusp appeared to be larger than those in the other two segments of the valve. The *aorta* was greatly dilated and showed extensive atheromatous change of the intimal coat. There were no gross signs of fatty degeneration of the muscle.

The left lung showed extensive consolidation and a large cavity in the lower lobe. In the upper lobe there were some more recent areas of tuberculous consolidation and scattered between these were miliary tubercles. There was no lesion in the right lung, and no further evidence of tuberculosis in the body.

Histology.

The *right auricle* was sparsely infiltrated with lymphocytes and there was an increase in the amount of fibrous tissue over a considerable portion of the muscle. The muscle fibres themselves appeared to be normal for the most part, though in one or two places a few fibres could be found which appeared to be shrunken and stained in a manner which suggested conversion into fibrous tissue. The *sino-auricular node* showed neither infiltration nor fibrosis, and in the sections examined appeared to be normal in every way. The *left auricle* showed no changes in histological character which call for comment. The *central fibrous body* showed small perivascular infiltrations in many of the sections examined and the vessels over a large area were much more prominent than usual.

The *auriculo-ventricular node and bundle* showed a series of small but quite well defined lymphocytic infiltrations which were much more frequently met with at the upper and posterior portion of the node than in any other situation. The whole of the node and bundle showed a sparse infiltration with lymphocytes, but so scanty as to be reduced to half a dozen cells in some sections. The branches of the bundle were not equally affected in that no extraneous cells of any kind were found in the right branch, while on the left side a definite infiltration was found. In addition to this the vessels in the neighbourhood of the left branch were definitely congested and the wall of the main arteriole of that region was to a great extent converted into fibrous tissue. There were many points in the node and bundle where the constituent cells of the vessel walls were evidently in a state of activity, but the occurrence of this condition was quite irregular. The microphotograph reproduced in Fig. 4 shows a typical example of the peri-vascular infiltrations at the upper limit of the node.

There was nothing in the appearance of the muscle fibres of the node which calls for comment.

The *ventricular muscle* was apparently normal as regards the fibres themselves. The fibrous tissue elements here and there were rather more noticeable than usual, but the change could not be said to amount to a definite fibrosis. The *vessels* of the heart showed a quite irregularly distributed sclerotic condition, and in a good many places the constituent cells of the walls of the smaller vessels were evidently in a condition of proliferation. The *valves* showed nothing beyond sclerosis, and no recent changes. The endocardium in general showed nothing but blood staining. Fatty degeneration could not be demonstrated histologically.

The condition of the heart may be summed up as being one of inflammation manifested by lymphocytic infiltrations which are most obvious at the upper and posterior part of the auriculo-ventricular node and by irregularly distributed changes in the vessels, unaccompanied by affection of the right branch of the bundle or by any definite alterations in the muscle fibres themselves.

Summary.

A case is described which showed paroxysmal heart-block and paroxysmal auricular fibrillation.

Histological examination showed that the musculature of the right auricle was affected by fibrosis and lymphocytic infiltrations, though the sino-auricular node was not actually involved. The auriculo-ventricular node and bundle were affected by infiltrations of lymphocytes and vascular changes throughout their whole extent with the exception of the right branch of the bundle. Nothing abnormal was found in the last named part of the conducting mechanism.

We are deeply indebted to Sir Robert Simon, under whose care the patient was, for permission to publish the case.

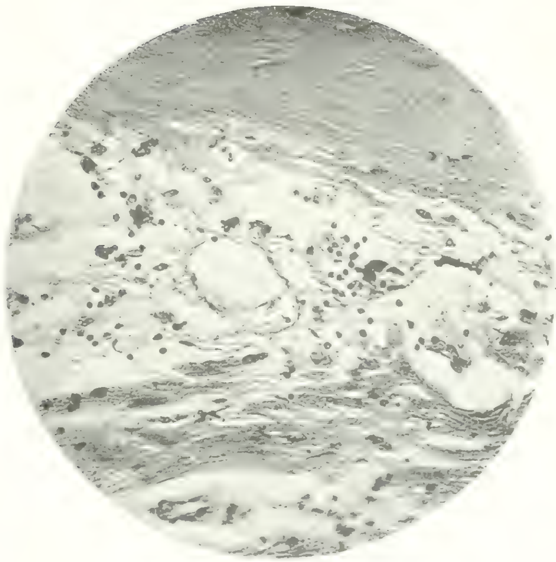


Fig. 4.

AURICULAR FIBRILLATION FOLLOWING COMPLETE HEART-BLOCK IN DIPHTHERIA.

By JOHN PARKINSON.

(*From the Cardiac Department of the London Hospital.*)

Charles B., aged 22 years, was admitted to the Neasden Isolation Hospital on November the 8th, 1913, suffering from pharyngeal diphtheria. There was no history of rheumatic fever nor of any other infection except measles. He had been ill for two days. A culture from the throat confirmed the diagnosis. Two doses of antitoxin, amounting to 10,000 units, were injected on the day of admission. He improved greatly within two or three days and had no further symptoms until November the 26th, when the glands of the neck became swollen and tender and there was some pain in the joints without swelling. The temperature rose to 102° F. The pulse rate increased during November the 26th to 29th, thus:—88, 96, 124 per minute. On November the 30th, the twenty-third day of the disease, it was noticed that the pulse had fallen to 62 although the pyrexia continued. The temperature became normal on December the 3rd, but the slow pulse (50-60) persisted. On December the 7th, I first saw the patient and took polygraphic tracings. These showed the presence of *complete heart-block* with a ventricular rate of 53 (Fig. 1). The rate of the auricle was approximately 82, and a sinus arrhythmia would explain the slight variation in the *a-a* intervals. The patient was comfortable and did not notice any symptoms during the changes in the heart rhythm.

On December the 11th, four days later, he was again visited and further polygraphic records were made. The pulse was found to be completely irregular and about 50 per minute. A tracing showed the presence of *auricular fibrillation* (Fig. 2). No further changes were noted in the patient's condition. He was kept under observation longer than usual as a precautionary measure and was discharged on January the 17th, 1914, after ten weeks in hospital.

On January the 21st, 1914, three days after his discharge, he came to the Cardiac Department of the London Hospital for further examination. An electrocardiogram was taken, which confirmed the presence of auricular fibrillation. The rate was then 100 per minute, about twice the rate in the first few days of the onset of fibrillation after the heart-block. The patient looked and felt quite well. The apex beat of the heart was in the fifth space half-inch internal to the nipple line. The heart sounds, though occurring at irregular intervals, were normal in character and unaccompanied by murmurs.

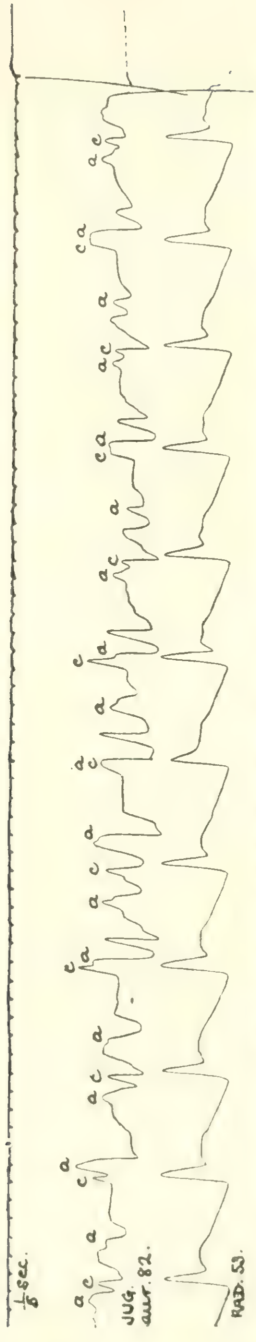


Fig. 1. A polygraphic tracing taken on December the 7th, 1913. It shows complete heart-block with a ventricular rate of 53.

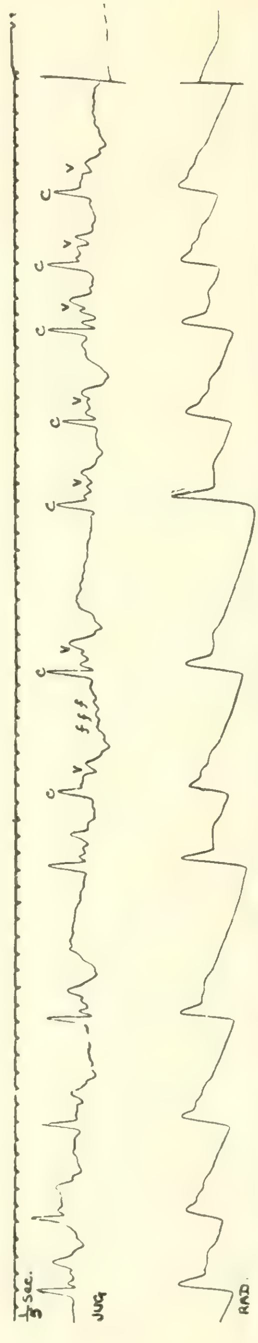


Fig. 2. A polygraphic tracing taken on December the 11th, 1913, four days after Fig. 1. It shows the irregular pulse of auricular fibrillation with absence of the auricular summit and the presence of fibrillation waves (f).

On March the 14th, 1914, a month after discharge from hospital, he was again examined. He felt quite well and had returned to his work of "watching" and oiling machinery. In the previous week he had taken a five mile walk without shortness of breath or undue exertion. On examination he looked quite well. The physical signs were the same as on January the 21st. The ventricular rate was 94 per minute. An electrocardiogram showed that auricular fibrillation was still present.

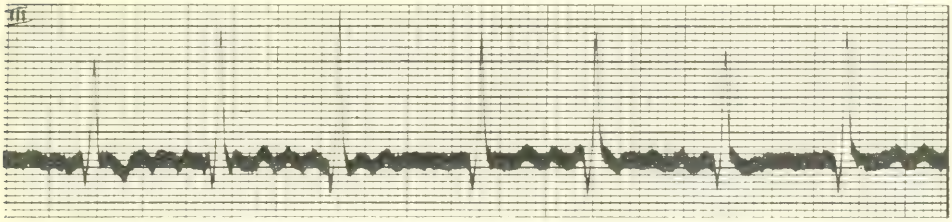


Fig. 3.

On June the 3rd, 1914, six months after the onset of auricular fibrillation, he was again seen. He was still at work and had experienced no symptoms. He had taken a seven-mile walk the day before without any shortness of breath or palpitation. The physical signs were exactly the same as on his discharge from hospital and the apex beat was in the same position. An electrocardiogram (Fig. 3) showed that auricular fibrillation was still present. The rate was 100-110 per minute.

Remarks.

This appears to be the first undoubted case in which auricular fibrillation is recorded as developing during diphtheria. Its onset a few days after the occurrence of heart-block is interesting. The ventricular rate remained slow (50 per minute) for some days after auricular fibrillation occurred, probably owing to persistence of heart-block. The rate increased during convalescence to 100 per minute.

In a fatal case described by Price and Ivy Mackenzie[5] heart-block was probably present, but no definite evidence of auricular fibrillation was produced.

Cases of heart-block in diphtheria have also been described by Magnus-Alsleben,[4] Fleming and Kennedy,[1] Hume,[3] Röhmer[6] and Hecht.[2]

My thanks are due to Dr. W. F. V. Simpson, then Acting-Superintendent of the Neasden Isolation Hospital, for his kindness in drawing my attention to this case and affording me facilities for its investigation.

BIBLIOGRAPHY.

[1] Fleming and Kennedy. Heart, 1910-11, ii, 77.

[2] Hecht. Ergebn. der inner. Med. u. Kinderheilk., 1913, xi, 324.

[3] Hume. Heart, 1913-14, v, 25.

[4] Magnus-Alsleben. Zeitschr. f. klin. Med., 1910, lxix, 82.

[5] Price and Ivy Mackenzie. Heart, 1911-12, iii, 233.

[6] Röhmer. Verhandl. der Gesselsch. f. Kinderheilk., 1911, xxviii, 279

[7] Röhmer. Jahrb. f. Kinderheilk., 1912, lxxvi, 391.

[8] Röhmer. Zeitschr. f. exper. Pathol. u. Therap., 1912, xi, 426.

[9] Sperk. u. Hecht. Zentralbl. f. Kinderheilk., 1912, xvii, 309.

REPORT OF A CASE SHOWING PREMATURE BEATS ARISING IN THE JUNCTIONAL TISSUES.

By F. N. WILSON.

(*Department of Internal Medicine, University of Michigan.*)

PREMATURE beats arising in the junctional tissues between the auricles and ventricles are comparatively rare in man. Previous to the use of the string galvanometer for the study of cardiac irregularities the diagnosis of such premature beats rested mainly upon the form of the venous tracing. Where both auricles and ventricles contracted prematurely and where these contractions were simultaneous, or the intervals separating them were less than normal, it was assumed that the abnormal impulses giving rise to these contractions arose in the junctional tissues. Cases of this sort have been reported by Mackenzie,[14] Hering and Rihl,[5] and recently by Laslett.[8] In such cases the *a* and *c* waves on the jugular pulse are not as a rule separately distinguishable, but are usually represented by a tall composite wave, which occurs before the time when a normal auricular wave could be expected.

With the advent of the electrocardiograph for the study of cardiac irregularities new criteria for the recognition of premature beats arising in the junctional tissues became available. Where the auricular beat preceded the ventricular the electrical complex due to this beat may be inverted. Lewis[9] reported a case showing such premature beats and also pointed out their occurrence in curves published by James and Williams.[6] The inversion of the electrical complex was attributed to an origin of the stimulus in the region of the junctional tissues, rather than in its normal site in or near the sinus node.[10] That inversion of the auricular electric complex may be produced by stimuli entering the auricles by way of the junctional tissues is shown in the curves exhibiting reversal of the cardiac mechanism which have been published by James and Williams.[7]

Where the ventricular contraction precedes the auricular a normal ventricular complex indicates a supraventricular origin of the stimulus and shows that the premature beat must have had its origin in the junctional tissues. Two such cases have recently been reported by Lewis,[11] and by Lewis and Allen.[12] In these the premature ventricular contractions did not interrupt the normal rhythm of the auricles. In the available reports I have

been unable to find any case in which a premature contraction of the ventricle with a normal electrical complex was followed by a premature auricular contraction.

Premature beats arising in the junctional tissues have been studied experimentally by Rothberger and Winterberg,[16] by Lohmann,[13] by Hering,[4] and by Lewis.[9] Hering[3] concluded from his observations that the main delay in the passage of impulses from auricles to ventricles occurred in the auriculo-ventricular node. A premature impulse arising in this node might therefore give rise to simultaneous contractions of auricles and ventricles or to premature beats showing either a shortened *As-Vs* interval or a *Vs-As* interval.

Case report.—Mr. J. C., a farmer, age 72, entered the University Hospital on March the 11th, 1914, complaining of a burning sensation over the abdomen and lower thorax.

His father died of tuberculosis at 56 and his wife died of the same disease at 67. The family history was otherwise negative. The patient had had measles, mumps, malaria, typhoid and pneumonia. He denied venereal disease and alcoholism. He used tobacco to excess. The illness for which he came to the hospital started in August, 1913. At that time he began to have a burning sensation over a small spot just under the left costal border. This sensation was made worse by exercise. The area over which the abnormal sensation was felt gradually became larger until it included the left abdomen and lower left thorax. In July, 1913, he had an attack of unconsciousness, which lasted about one hour, and upon recovering from this he was somewhat short of breath. He gave up work about one week before entering the hospital because of dyspnœa and weakness. He had been getting up several times at night to urinate and passed large amounts of urine during the day. He also complained of some dribbling after micturition. He had never had any œdema or chronic cough. He had broken many bones at various times by slight injuries, and among them his left arm, ankles, fingers, clavicles, scapula, and several ribs.

Examination showed an old man with the characteristic tremor of paralysis agitans. The peripheral vessels were very sclerotic. The lips were slightly cyanosed. The patient showed a marked kyphosis involving almost all of the thoracic vertebræ. The thorax was somewhat emphysematous. There was tenderness along the costal nerves over the lower part of the precordium. The heart apex was 2½ cm. outside the nipple line in the fifth intercostal space and the apex impulse was forceful. On auscultation the aortic second sound was accentuated; no murmurs were heard. The dominant rhythm was interrupted frequently by premature beats. The abdomen was negative except for tenderness over the left side, where the patient complained of paræsthesia. The blood pressure was 170 mm. Hg.. The urine was negative except for finely granular casts. The blood and stools were negative. Fluroscopic examination of the chest showed a moderately enlarged heart in a transverse position and some widening of the aortic arch. An X-ray plate of the lungs was negative. Electrocardiographic records were taken on the day the patient entered the hospital and on several later occasions over a period of one week. Simultaneous venous tracings were taken on most occasions.

Description of curves and discussion.

Premature beats arising in the junctional tissues between the auricles and ventricles usually show several or all of the following characteristics. 1. Both auricles and ventricles contract prematurely. 2. The *As-Vs* or the *Vs-As* interval is shortened. 3. The auricular complex in the electrocardiogram is inverted. 4. The ventricular complex is normal or nearly normal. For various reasons one or other of these criteria may be absent. The extrasystoles from our patient illustrated a variety of types and these will be discussed in order.

Fig. 1 shows a premature contraction of both auricles and ventricles. The ventricular complex is normal and the auricular wave P is inverted. The P-R interval is shortened, being 0·11 seconds as compared with his normal interval of 0·17 seconds. It therefore fulfills the criteria given above and represents a typical extrasystole arising on the auricular side of the junctional tissues. Fig. 2 shows a normal ventricular complex which is slightly premature (0·08 seconds). No P wave is seen, but from the venous tracing it is evident that the auricle contracted at the normal time. To explain the absence of the P wave on this electrocardiograph tracing we may assume that the ectopic auricular stimulus arising in the junctional tissues occurred at about the same time as the normal auricular stimulus, originating in the sinus region, and that the electrical effect of the two neutralised each other. The auricles therefore contracted at the normal time but produced no well defined movement of the galvanometer string. The possible explanation that this was an auricular extrasystole with an isoelectric auricular complex seems improbable, since the a-c interval of the venous curve is less than normal.

Fig. 3 shows an extrasystole in which the ventricular complex is nearly normal, R being somewhat taller and S somewhat shorter than usual. In this case no auricular complex is plainly distinguishable in the galvanometer tracing but the venous tracing shows a very tall wave which is evidently due to a premature auricular contraction following the ventricular systole. It is preceded by a small c wave. Here, therefore, we have a premature contraction of both ventricles and auricles, with a c-a interval decidedly less than the normal a-c interval. This fact, taken in connection with the normal ventricular complex on the electrocardiogram, makes it certain that this extrasystole arose in the junctional tissues. It differs from the extrasystoles of the type shown in Fig. 1 in that it arose on the ventricular side of the junctional tissues.

This patient also showed a number of premature contractions where the interpretation was more difficult and less certain. These were characterised by (1) premature contractions of both ventricles and auricles, (2) abnormal ventricular complexes, and (3) shortened Vs-As intervals. The measurement of the Vs-As interval in these abnormal contractions was difficult both in the galvanometer tracings and in the venous curves when either was taken alone. In the former it was difficult to identify P when it occurred during the abnormal ventricular complexes. In the latter the c-a interval may be shortened owing to the fact that the c wave of abnormal ventricular beats may be unusually delayed in the venous tracing[10]. With simultaneous venous and galvanometer records, however, it is possible to measure fairly accurately the difference in time between the onset of the electrical ventricular complex and the jugular a wave. By allowing for the difference in time between the galvanometer and the venous records one may then estimate the Vs-As interval. Examples of the premature beats here described are

shown in Fig. 4, 5 and 6. Our estimate of the *As-Vs* intervals in these as well as in our other figures is shown in the following table :—

	Fig.	*a-c*	*P-R*	*a-R* (corrected)
Normal	1	0·175	0·175	0·175
Abnormal	1	0·112	0·112	0·112
..	2			0·095
..	3	—0·075		—0·075
..	4	—0·100		—0·112
..	5			—0·125
..	6 (a)			—0·135
..	6 (b)			—0·150

In the abnormal beats shown in Fig. 4, 5 and 6 the premature contractions of both ventricles and auricles, associated with a shortened *Vs-As* interval, favours the view that these beats originated in the junctional tissues. If one had at hand only the venous tracings, a diagnosis of premature beats arising in the junctional tissues would have been made without question. Yet the abnormal ventricular complexes in the galvanometer tracings would seem to indicate that the beats arose not in the junctional tissues but in the walls of the ventricles or in branches of the His bundle. If one adopts the hypothesis that these ectopic beats arose in the ventricular wall, the subsequent premature auricular contractions with shortened *Vs-As* intervals can hardly have been due to retrograde stimulation of the auricles. This condition is always rare and never, so far as we know, occurs with a shortened *Vs-As* interval. It is possible, however, that premature ventricular contractions may have induced premature auricular contractions mechanically, as suggested in a case of complete heart-block referred to by Cohn.[1]

It is also possible to interpret these tracings as unusual examples of premature beats arising in the junctional tissues. In order to explain the abnormal type of ventricular complexes in accordance with this hypothesis, it would be necessary to assume either that the conduction of the impulses in branches of the His bundle was impaired or that the beats instead of arising in the main bundle originated in one of its branches. Abnormal ventricular complexes apparently due to impaired conduction in branches of the His bundle have been reported by Lewis,[10] Rosenthal,[15] and others. In Rosenthal's case the abnormal ventricular complexes followed auricular extrasystoles. His patient exhibited other signs of imperfect conduction, such as blocked auricular extrasystoles. Most of the premature auricular beats were followed by nearly normal ventricular complexes, and the aberrant ventricular complexes occurred only rarely and always when the ectopic auricular beats occurred early in diastole and the junctional tissues

had had little time to recover. In the present case there was no other evidence of impaired conduction,* and the aberrant ventricular complexes did not as a rule occur earlier in diastole than did the normal complexes of Fig. 3. Furthermore, they always showed a somewhat longer *Vs-As* interval, indicating an origin in lower portions of the junctional tissues.

If the impulses giving rise to these beats arose in branches of the His bundle, this would explain the abnormal forms of the ventricular complexes,[2] and it might also account for the length of the *Vs-As* intervals which, though shorter than the normal *As-Vs* intervals, were always longer than the *Vs-As* interval of Fig. 3. The main objection to this interpretation arises from Hering's experimental evidence that most of the delay in the conduction of impulses from auricles to ventricle occurs in Tawara's node. If this be true, it is difficult to understand why a premature beat arising in the right or left branch of the His bundle should show a much shorter *Vs-As* interval than one arising in the walls of the ventricle. The fact that other parts of the auriculo-ventricular conduction system were giving rise to heterogenetic impulses in this patient supports the view that these unusual beats also arose from this system.

Summary.

A case is reported in which premature contractions occurred at different levels of the conduction system between the auricles and the ventricles. Where the auricular contractions preceded the ventricular contractions, *P* was inverted. In a single instance *P* disappeared, although the auricles contracted in presystole. Apparently there was interference between the normal contraction arising in the region of the sinus node and the abnormal contraction arising in the region of the junctional tissues. A premature ventricular contraction with a normal ventricular complex is reported. This was followed by a premature auricular contraction with a shortened *Vs-As* interval. In other instances the premature contractions of both ventricles and auricles with shortened *Vs-As* intervals were accompanied by abnormal ventricular complexes. The interpretation of these is discussed.

BIBLIOGRAPHY.

1 Cohn and Fraser. Heart, 1913-14, v, 141.

2 Eppinger and Rothberger. Zeitschr. f. klin. Med., 1910.

3 Hering. Arch. f. d. ges. Physiol., 1910, cxxxi, 572, lxx, 1.

4 Hering. Arch. f. d. ges. Physiol., 1909, cxxvii, 155.

5 Hering and Rihl. Zeitsch. f. exper. Pathol. u. Therap., 1906, ii, 510.

6 James and Williams. Amer. Journ. Med. Sci., 1910, cxl, 644.

7 James (Henry) and Williams. Heart, 1913-1914, v, 109.

* An increased *As-Vs* was found on one occasion when an auricular premature beat occurred very early in diastole so that *P* fell upon the previous *T*.

[8] LASLETT. Quart. Journ. Med., 1912-1913, VI, 209.

[9] LEWIS. Heart, 1909-10, I, 306.

[10] LEWIS. "Mechanism of the Heart Beat," London, 1911.

[11] LEWIS. Quart. Journ. Med., 1911-1912, V, 1.

[12] LEWIS AND ALLEN. Amer. Journ. Med. Sci., 1913, CXLV, 667.

[13] LOHMANN. Arch. f. Anat. u. Physiol. (Phys. Abth.), 1904, 431.

[14] MACKENZIE. Quart. Journ. Med., 1907-1908, I, 131.

[15] ROSENTHAL. Amer. Journ. Med. Sci., 1911, CXLII, 788.

[16] ROTHBERGER AND WINTERBERG. Arch. f. d. ges. Physiol., 1910, CXXXV, 506.

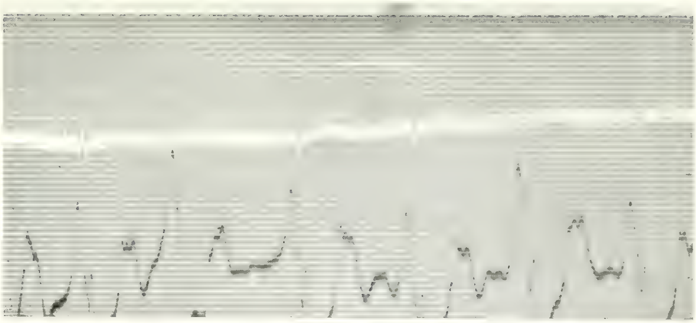


Fig. 1. In this as in all the figures, lead *II* was used: the sensitivity of the galvanometer was 15 mm. = 1 millivolt, and the time marker registered one-fifth seconds. Simultaneous venous tracings are shown. The second beat shows an inverted auricular complex, a normal ventricular complex, and an *As-Vs* interval of 0·11 seconds. In all tracings the normal *As-Vs* interval was 0·17 seconds.

Fig. 2. The third ventricular complex is premature by about 0·08 seconds and is preceded by no *P*. The venous curve shows a tall *a* wave at the normal time.

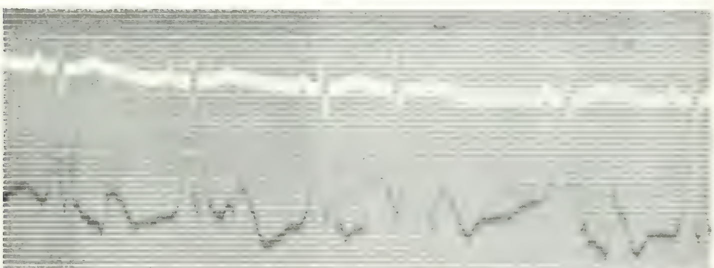


Fig. 3. The fourth ventricular complex is premature and slightly abnormal, showing a taller *R* and a shorter *S*. In the venous tracing is seen a small *c* wave followed by a tall premature *a* wave. The *Vs-As* interval is much shorter than the normal *As-Vs* interval.

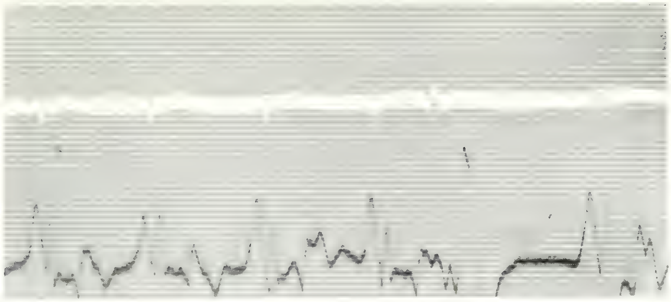


Fig. 4. The fifth ventricular complex is abnormal, showing an unusually prolonged primary deflection whose amplitude is not increased. The venous curve shows a small *c* wave followed by a tall premature *a* wave, with a Vs–As interval of 0·11 seconds.

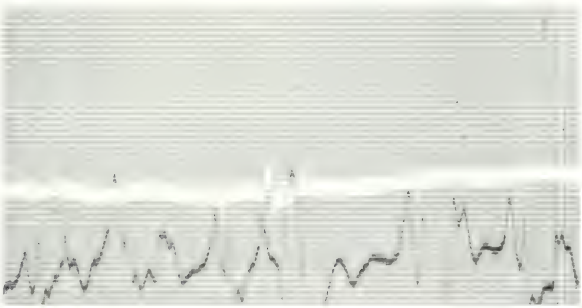


Fig. 5. The fourth ventricular complex is premature and abnormal. The venous curve shows a tall premature *a* wave which definitely follows the primary electrical deflection. The Vs–As interval was estimated to be 0·125 seconds.

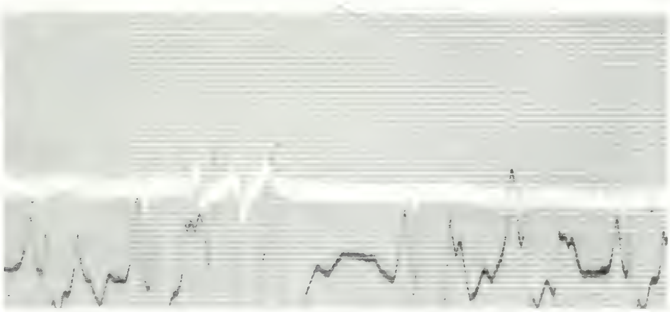


Fig. 6. The third (*a*) and fourth (*b*) ventricular complexes are abnormal and resemble closely ventricular complexes due to premature beats arising in the right and left ventricles respectively. In the venous curve a tall *a* wave follows each.

TACHYCARDIA OF AURICULAR ORIGIN AND FLUTTER WITH PHASIC VARIATION IN AURICULAR RATE AND IN CONDUCTION.

By JOHN PARKINSON and H. H. MATHIAS.

(*From the Cardiac Department of the London Hospital.*)

Louise M., aged 20, single, a vellum stitcher, was admitted to the London Hospital on October the 7th, 1913, under the care of Dr. James Mackenzie. She complained of pain in the "stomach" and back, and of throbbing in the chest.

History.

She was quite well until October the 6th, the day before admission, when she awoke with severe toothache which disappeared during the morning. At noon, on rising suddenly to answer the door, she felt giddy and noticed a beating in her chest, which continued for five or ten minutes and then passed away. She felt sick and ill throughout the afternoon and experienced some abdominal pain of a "twisting" nature. She vomited three times during the evening but slept well that night. During the next morning, the day of admission, the abdominal pain and nausea returned. When she got out of bed "everything went dark" and she remembered nothing more. Her mother found her lying on the floor and she remained unconscious for some minutes. When she recovered she noticed a thumping in her chest. For a few moments it was rapid and then her heart gave a jump and became slow. When this occurred the throbbing sensation moved to the head and face. The slow beating felt in the head lasted for only a very short time; in her own words "as soon as it went to my face and head it went down to my chest again and beat quickly." This alternation persisted up to the time of her admission. The doctor considered the case to be appendicitis and would have treated her at home, but because of the condition of the heart, he advised her removal to hospital.

Previous health.

She had never before experienced any attack such as that for which she was admitted, nor was there any history of a similar condition among her relatives. As a child she was healthy. There was no history of rheumatic fever, scarlet fever, or diphtheria. In 1911 she had an attack of indigestion with epigastric pain and vomiting, which lasted for a fortnight; and again in 1912 she had a similar but milder attack lasting a week. Apart from these attacks her general health and digestion had always been good.

Condition on admission, October the 7th, 1913.

The patient was a slightly built girl of cheerful disposition, who did not appear to be seriously ill: she could walk a little without discomfort. She complained of headache, abdominal pain, and throbbing in the chest. She could lie flat without distress. The breathing was rapid, 37 per minute, but there was no subjective shortness of breath. The temperature was 98° F. (36·7° C.). The face was flushed and the skin was warm and moist. Cyanosis was absent. There was slight œdema of the ankles. No pulsation was seen in the neck. Some epigastric pulsation was seen; it was most noticeable when the heart was beating slowly. The apex beat could be seen and felt in the fourth left intercostal space just inside the mid-clavicular line, 3½ inches (9 c.m.) from the middle line. There was a small area of

visible pulsation, without palpable impulse, in the fifth space directly below this point. No thrill was felt. The right limit of deep cardiac dulness in the fourth space was 1¼ inches (3·2 c.m.) from the middle line. The upper limit reached the third left rib, the left limit was 3½ inches (9 c.m.) from the middle line. The heart sounds were clearly heard over the whole præcordia and were unaccompanied by murmurs. The second sound in the pulmonary area was louder than in the aortic area. During auscultation the rate of the heart varied greatly, for a few beats it was slow and then gradually quickened until it was rapid. This rapid rate continued for a few moments, when suddenly the heart again began to beat slowly. The rate then gradually increased until it was very rapid and so the same periodic irregularity was repeated indefinitely. Details of the actual variations are given in the description of the records. The lungs showed no abnormal signs. The abdomen appeared normal on inspection. A band of skin which reacted excessively to the dragged point of a pin, extended round the right side of the trunk to the back, and apparently corresponded to the area supplied by the ninth and tenth thoracic nerve roots. On palpation of the abdomen she complained of pain and contracted her abdominal muscles. This tenderness was most conspicuous around the umbilicus, and especially to the right of it. When her attention was distracted, it was possible to palpate the whole abdomen without difficulty. Nothing abnormal was felt. The liver and spleen were not palpable, nor were they enlarged to percussion. The flanks were resonant. The urine contained neither albumen nor sugar.

Course.

The size of the heart to physical examination did not alter. Crepitations were never heard in the lungs. The liver and spleen were never found to be enlarged. The band of hyperalgesia was only found on the day of admission. The urine remained normal. The œdema disappeared during the night of admission and did not recur. On the same evening she vomited once while being examined but slept well.

On the morning of October the 8th she felt more comfortable, though she still complained of headache. The pain in the abdomen and back had almost disappeared, but the throbbing in the chest continued and the face was still flushed. The rate of respiration was 28 per minute. The abdomen was no longer tender and only slightly rigid on palpation.

On October the 9th the headache and throbbing were still present. The abdomen was flaccid and free from tenderness.

On October the 10th she looked and felt better. She did not complain of the throbbing in the chest so much and the headache had disappeared. This was the last day on which the periodic irregularity was observed. All records from October the 7th to October the 10th had shown their continued presence.

From October the 11th to the 19th she felt quite well and complained of no abnormal sensations beyond occasional momentary thumping in the

chest. Electrocardiograms during this time showed short paroxysms of auricular tachycardia in which the rate was constant (Fig. 8). She recognised the moment when these attacks began, but thought they ended several beats before the attack actually ceased, as shown by polygraphic tracings. When attacks were few, on the days during which they occurred, they could be elicited at will by such exertion as sitting up in bed two or three times in succession. On one such day the excitement of transfer to another ward appeared to produce a prolonged attack. We noticed a slight change of facial appearance on the days during which attacks occurred. The face was slightly flushed and she had a rather shy expression. This combination was so characteristic that one always knew on entering the ward whether she was experiencing attacks or not. On the days during which paroxysms could not be found, exertion and excitement failed to produce them.

On October the 20th she felt quite well. A Wassermann reaction with Sachs' antigen on this date was negative. Apart from short attacks of throbbing on October the 23rd, 27th, 28th, 29th and November the 5th, she felt well and was discharged on November the 8th, 1913, having had no attacks for three days.

Since her discharge short paroxysms have occurred on several occasions. During the first fortnight after leaving hospital she occasionally experienced attacks lasting a few seconds, and one attack on November the 17th, following over-exertion, which lasted four or five minutes. After this attack she was well until November the 19th. Between 6.30 that evening and 3 o'clock the following afternoon she had frequent attacks lasting a few seconds. She had one further series of attacks from December the 31st, 1913, to January the 2nd, 1914. The paroxysms occurred every ten minutes or so and lasted three to four minutes, but the discomfort was slight and did not prevent sleep. Apart from these attacks she has remained well up to the time of her last visit, March the 2nd, 1914.

Description of records.

From October the 7th, the day of admission, until October the 10th the radial pulse was changing its rate repeatedly, being found slow at one moment and rapid the next. Polygraphic tracings showed that the curious auscultatory phenomena and the varying character of the radial pulse were due to changes repeated periodically almost exactly every two or three minutes. Pressure on the right and on the left vagus was tried while an electrocardiographic film was being taken. The result was negative, but the patient was intolerant to pressure.

Several complete periods of irregularity were recorded by the polygraph, and long samples of similar periods by the film camera of the electrocardiograph. The following account is founded upon these records, obtained during the first four days after the patient's admission. It will be convenient to divide the period of irregularity into four phases. A typical period, as shown by the electrocardiograph, is illustrated by two long pieces of film, one

embracing phases I and II (Fig. 2, 3, 4), the other phases III and IV (Fig. 5, 6). All tracings taken during the four days showed the continued presence of exactly similar periods of irregularity.

Phase I. Tachycardia of auricular origin, with increasing rate.

Phase II. Abnormal ventricular contractions.

Phase III. Auricular flutter and heart-block.

Phase IV. Auricular slowing.

Phase I. Tachycardia of auricular origin, with increasing rate (*Fig.* 2, 3, 4). At the end of phase IV, the last of the previous period, the auricle beats at about 60 per minute and the *P*'s are inverted. The onset of tachycardia occurs without any change in the auricular complex—it remains inverted. The auricular (and ventricular) rate suddenly rises from about 60 per minute to 140 per minute, and this marks the beginning of phase I. The rate steadily increases from 140 to 170 or 180 per minute, when *alternation* appears in both radial (Fig. 1) and electrocardiographic tracings (Fig. 3). It is seen about 50 seconds after the beginning of phase I. With alternation present the rate continues to increase as before until at last a rate of 240 is reached. The whole of phase I occupies 70-90 seconds.

The records of this phase show that the increase in rate is gradual. Thus in Fig. 2 the increasing rate leads to a gradual fusion of *P* and *T* with the production of an isoelectric curve. As the rate further increases *P* emerges between *R* and *T* of the preceding beat. Later still, with an auricular and ventricular rate of 225, as at the end of Fig. 3 and as in Fig. 7, an appearance of "1 : 1 auricular flutter" is produced. In phase I of the cycle shown in Fig. 2, 3 and 4, the rate, reckoned from consecutive intervals of six seconds, increases thus: 155, 175, 195, 210, 225 and 240 per minute. Another period, of which a part is shown in Fig. 7, shows a similar increase of 184, 192, 204, 218 and 225 per minute. In one strip of radial tracing the rate, reckoned from consecutive intervals of six seconds, is 150, 154, 160, 165, 175, 185 per minute. At 175 conspicuous alternation of the pulse appears rather suddenly (Fig. 1).

Phase II. Abnormal ventricular contractions (*Fig.* 4). When the auricular and ventricular rate reaches 240 per minute a few single abnormal ventricular contractions appear, interspersed between the ordinary beats of phase I. Phase II lasts about 6-18 seconds.

In Fig. 4 the first change noticed is the occurrence, after a short pause, of a slightly different ventricular complex from that obtaining in phase I. The *R* summit is higher and *Q* and *S* are more pronounced. This changed ventricular complex will be seen to continue throughout phase III; it may depend merely on the longer pause preceding it. After the beat described

there are five $Q\ R\ S$ complexes like those of phase I, and then another modified one which is followed by an abnormal ventricular contraction. Two more occur in this phase, each preceded by the modified $Q\ R\ S$ complex. In only one film were two successive abnormal ventricular contractions seen.

Certain groups of phase II space exactly and spacing is present in two other unpublished records of this stage. When heart-block in phase III discloses inverted *P's* there are found to be 240 per minute, occurring at the same rate as at the end of phase I. So it is probable that the auricular rhythm continued unchanged through phase II. Had not the spacing and continuity of rate been present, this phase might have been interpreted as auricular fibrillation, on account of the irregularity of the inter-ventricular curve.

Phase III. Auricular flutter and heart-block (*Fig.* 4 *and* 5). Immediately after the last premature ventricular contraction the auricular rate is 240 per minute and every second auricular beat is blocked. The ventricular complexes are all of the modified character described under phase II. In addition to 2 : 1 block, an example of 3 : 1 block is seen and a long ventricular pause during which five or six inverted *P's* occur. Phase III lasts about 6-9 seconds. The auricular rate gradually decreases, *while the* 2 : 1 *block continues,* to a rate of 200 per minute. A long auricular pause then marks the beginning of phase IV.

Phase IV. Auricular slowing (*Fig.* 5 *and* 6). The auricular rate varies greatly. At some periods the rate is 150 per minute for a few beats, but for the most part there are pauses of ½-1 second or more. The longest *P-P* interval is 1·3 seconds, corresponding to an auricular (and ventricular) rate of 46 per minute. Phase IV lasts for about 15 seconds. *P* is usually inverted, but occasionally, three times in Fig. 6, it is upright. When the *P* is upright the auricular rate varies, as when it is inverted. The return to an inverted *P* does not necessarily mark the onset of the returning tachycardia.

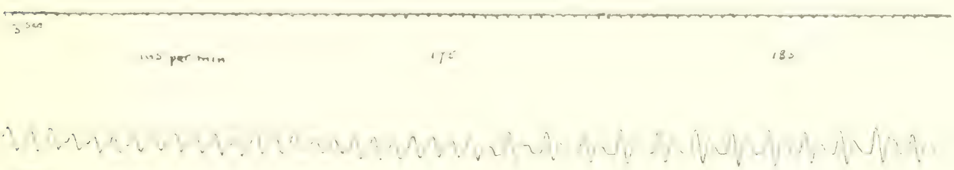


Fig. 1. A radial tracing of part of phase I showing the gradual increase of rate with development of pulsus alternans when it reaches 175 per minute.

This phase is followed by a return to phase I, with a tachycardia of auricular origin starting at 140 per minute. In this new period the increase in rate, reckoning from periods of six seconds, was 140, 148, 156, 162, 168, 174, 180 per minute to the end of the strip of film obtained.

Fig. 7 shows a portion of phase I in which the steady increase of rate produces an appearance of "1 : 1 auricular flutter" when the rate reaches 225 per minute (*cf.* end of Fig. 3). Fig. 8 is an example of the onset of the paroxysms which occurred later in the course of the disease. A normal auricular and ventricular complex is shown followed by a premature auricular contraction, and later by the onset of a paroxysm of auricular tachycardia. These paroxysms showed none of the special characteristics of those described above, and the rate was constant. Fig. 1 is a radial tracing showing the occurrence of pulsus alternans when the rate exceeded 175 per minute.

Remarks.

The chief feature of interest is the variation in auricular rate during a paroxysm of abnormal auricular contractions, with and without heart-block. Lewis has pointed out that a characteristic of paroxysmal tachycardia is the constancy of rate during the paroxysm and that posture and effort do not affect it. This is referred to the absence of nervous control over the ectopic site of impulse formation. The case here recorded appears to be an exceptional one in this respect. It is difficult to explain the extreme variation in rate on any other assumption than that the *abnormal site of impulse formation was under nervous control.* This also obtained while the phase of auricular flutter was present. The changing rate may have been due to removal of inhibitory influence or to increase in accelerator action ; perhaps both came into play during part of the cycle. The evanescent varying block of phase III was almost certainly effected by the vagus. The long pauses with 6 : 1 block might result from over action of the vagus when it began to control the auriculo-ventricular bundle. The extreme slowing of the auricle during phase IV, while the *P* wave of the electrocardiogram was still inverted, was probably also vagal. The inverted auricular complex, *P*, whenever clearly identified, was always of the same character.

Summary.

In a case of paroxysmal auricular tachycardia, cycles comprising four phases were repeated one after another for four days. In the first phase the auricular rate gradually rose from 140 to 240 per minute. The second was marked by the occurrence of several abnormal ventricular contractions. The third showed auricular flutter with varying grades of heart-block, and the auricular rate fell during that period. In the fourth phase the block had ceased and the auricular rate varied from 50-150 per minute.

The variations in auricular rate are ascribed to nervous influence although the site of impulse formation was an abnormal one.

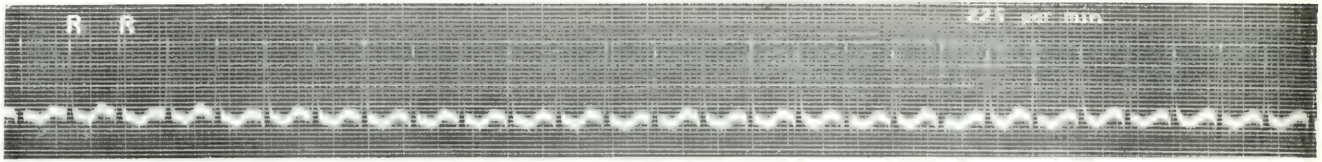


Fig. 7. An electrocardiogram showing phase 1, with a rate increasing to 225 per minute. It gives the appearance of 1 : 1 flutter.

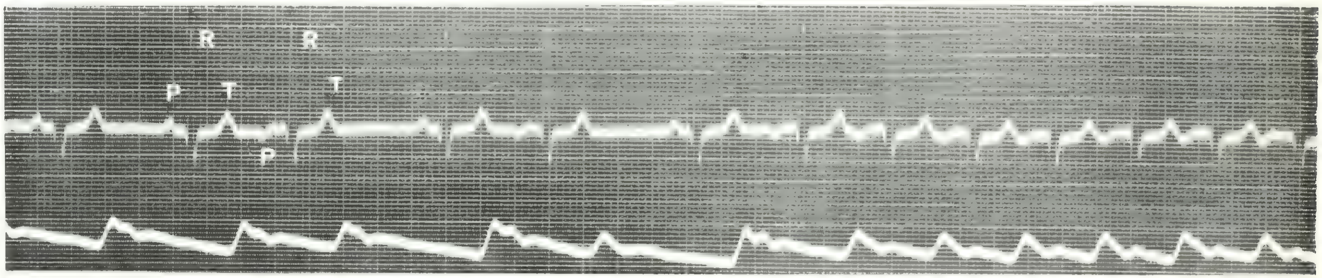


Fig. 8. An electrocardiogram with radial tracing taken later in the course of the illness. It shows the onset of one of the later paroxysms in which the rate was constant.

SUPPLEMENTARY NOTE ON A CASE OF HEART-BLOCK.

By T. WARDROP GRIFFITH.

WITH AN EXAMINATION OF THE AURICULO-VENTRICULAR JUNCTIONAL TISSUE.

By A. M. KENNEDY.

In a paper entitled "Remarks on two cases of Heart-Block," which was published in this Journal in February, 1912, I commented on the great difficulties which sometimes attend the distinction of a condition of partial heart-block from one of complete dissociation of auricular and ventricular action.

In the second case there were considerable periods of time when the only manifestation of impaired conductivity was the lengthening of the *a-c* interval; that is to say, every systole of the auricle was followed by a systole of the ventricle. There were many occasions, however, when the action of the ventricle was markedly infrequent, and where the tracings showed a numerical and time relationship between the auricular and ventricular contractions which raised, in a highly debatable form, the question of the block being a partial or a complete one.

If I were analysing the tracings again in the light of the somewhat fuller knowledge of the subject I now possess, I should incline to the view that some of the tracings which I regarded as indicating a partial block were really the records of a complete dissociation, but in the case of others I should adhere to my former opinion.

It is not, however, the object of this paper to attempt to clear up this obscurity, but to note the subsequent progress of the case and to put on record the report by Dr. Kennedy of the condition of the auriculo-ventricular junctional tissues of the heart.

The tracing bearing the latest date in my former paper was taken on May the 24th, 1911. The pulse was 62 per minute and the *a-c* interval was two-fifths of a second. During the next two years I saw the patient from time to time and tracings continued to show a somewhat similar condition.

On March the 22nd, 1913, he was admitted under my care, having had a severe attack of pain in the epigastrium with urgent dyspnœa. He went out very much relieved on the 23rd of April, but at the end of two days he had another attack, and was readmitted on April the 26th. He remained in the Infirmary till the date of his death on the 10th of July.

During both these periods a very large number of tracings were taken, and all of these showed a condition of complete heart-block. Except towards the end of life the pulse rate was usually about 40 per minute; on one occasion it fell to 33·3.

The condition of complete block is well shown in the tracing reproduced (Fig. 1). Here the ventricle is beating uniformly about 43 per minute, and the auricle at somewhat more than double this rate. The successive *a* waves of the series indicated by circles in the jugular tracing, that is to say every second wave, fall back relatively to each carotid wave, so that by the time we reach the carotid wave which corresponds to the 9th radial pulse, half an inter-auricular space has been lost. In the rest of the tracing, which is not reproduced, this ratio is maintained, and it is not, therefore, until we reach the 17th carotid wave that the exact relationship of *a* to *c* wave shown at the beginning of the tracing is repeated.

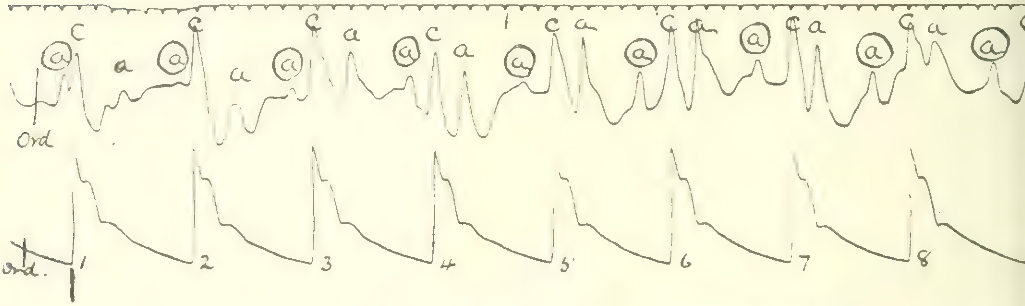


Fig. 1. 30-4-13. Auricular and ventricular rates as 33 is to 16.

At another time the ventricle was beating steadily at 37½ per minute, and the auricle at somewhat *less* than double this rate, but at a rate which varied slightly. Thus in one part of the tracing (which is not printed here) a composite wave, consisting of an auricular and carotid element, was repeated after four carotid periods, which exactly corresponded to seven interauricular periods. The auricle then began to beat a little more frequently, the rate of the ventricle being absolutely unaffected, so that the next composite wave did not occur till after the lapse of *five* carotid periods, which corresponded to *nine* interauricular spaces.

One day when the pulse was beating uniformly at 37½ per minute it was found that vigorous inhalation of nitrite of amyl, though it caused slight flushing of the face, did not alter the pulse rate by a fraction of a second. This is at variance with my own experience of the action of amyl nitrite in cases of heart-block, but must be regarded as additional evidence of the block being complete.

The special form of irregularity described by Wenkebach as occurring in cases of complete auriculo-ventricular heart-block was met with from time to time. The pause after the premature systole of the ventricle was sometimes exactly of the same length as the preceding and following periods; more usually it was slightly shorter. When a tracing of the venous pulse

was taken, as it was on many occasions, I think the evidence of a complete block was conclusive. This is seen in Fig. 2, which was taken on the 9th of June.

On July the 8th the patient had a severe syncopic attack ; my house-physician told me that for about a minute the pulse could not be felt, but that after a short time he counted it at about 100. At the end of some fifteen minutes it was beating at 56. He slowly went down hill and died on the afternoon of the 10th of July.

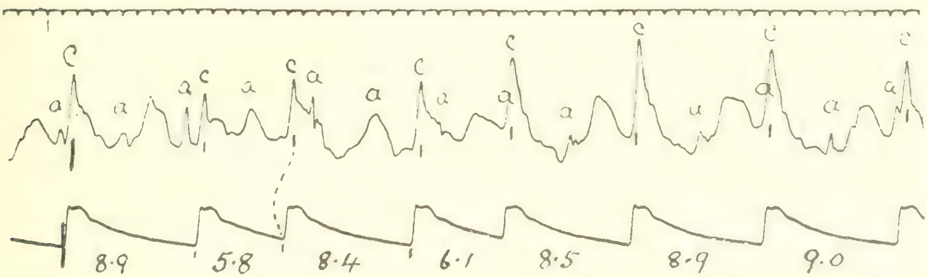


Fig. 2.

Some tracings of the radial pulse were taken on the day before he died. When the pulse was regular its prevailing rate was from 50 to 53 per minute. From time to time considerable lengths of the tracing showed alternate long and short pauses, the short being about three-fifths of a second and the long ones about one second. This I attributed to the rhythmical occurrence of premature beats of the Wenkebach variety, but the patient was too ill for satisfactory tracings of the venous pulse to be obtained.

At the autopsy the veins of the neck were found much distended. The heart was enlarged, there being great dilatation of the right ventricle, especially of the conus arteriosus. In the aortic sinuses of Valsalva, notably in the postero-left, in the adjacent part of the postero-right, and to a slighter extent in the adjacent part of the anterior there was a large patch of old-standing disease, where the coats of the vessel were thickened, raised, whiter than the surrounding vessel and opaque. This condition extended into the adjacent parts of the aortic valves and into the base of the anterior mitral segment, where there was great thickening of the tissues. I formed the opinion that the aortic leak had been mainly caused by the puckered condition of the postero-right and postero-left segments. On the left aspect of the ventricular septum there was a patch of endocardial thickening, due probably to the impact of the regurgitant stream. The coronaries showed some patches of disease. The further examination of the heart was entrusted to Dr. Kennedy, whose report follows.

Dr. Kennedy's report.

From the presence of the bulky fibrosis at the base of the anterior mitral cusp one could expect grave interference with the continuity of the specialised conducting tissue between auricles and ventricles, and confirmation of this expectation was obtained in a microscopical examination of the auriculo-ventricular node and bundle.

For this purpose a block of tissue was removed from the cardiac septum containing the pars membranacea septi, the adjacent portions of the auricular and ventricular muscular septa, the central fibrous body and the attachments of the anterior cusp of the mitral valve, and the septal cusp of the tricuspid valve. The block extended sufficiently far back to include the mouth of the coronary sinus and was cut out in such a manner that its long antero-posterior diameter was at right angles to the long axis of the heart. Such a block contains the whole of the *A-V* node and bundle and a considerable portion of the two principal branches of the latter. It was embedded in paraffin and cut in serial sections from above downwards, in the horizontal plane.

Microscopical examination of the sections demonstrates enormous fibrosis, dense and hyaline, at the base of the anterior mitral cusp spreading into the cardiac tissue and across the membranous septum which is in consequence greatly thickened. The fibrosis spreads into the node and replaces a portion of it. Leaving the node, the bundle is found to be much narrowed and pushed over towards the right side of the septum by the bulky fibrosed mass. A short distance below the node the bundle fibres are fibrosed for a small interval of their course and then, passing onwards, they very soon become lost in the dense mass of fibrosis which completely replaces the lower part of the main stem and its bifurcation. On passing below the mass of fibrosis the left branch of the bundle can be seen under the endocardium, but the right branch cannot be picked up. In the cardiac tissue beneath the fibrosis and bordering on the bundle some inflammatory cellular reaction (round-cells) is present in the neighbourhood of small arterioles.

A microscopical examination of the sino-auricular node was next undertaken, and for this purpose a block of tissue was removed from the junctional region of the right auricle with the superior vena cava, embedded in paraffin, and cut in serial sections. Examination of the sections shows the sino-auricular node to be normal.

The complete interruption of the continuity of the *A-V* bundle by fibrosis now demonstrated would account for the comp'ete heart-block noted during life. Although the fibrosis is undoubtedly of considerable duration, the presence of inflammatory cells in the cardiac tissue bordering the fibrosis is suggestive of some degree of activity in the process ; in other words, that it was progressive, and it is possible that formerly the interruption of the bundle was less complete with a corresponding less complete degree of heart-block.

OBSERVATIONS ON THE THIRD HEART SOUND.

By E. W. BRIDGMAN.

(*The Johns Hopkins Hospital.*)

It is my pleasure to note at the beginning of these Observations on the Third Heart Sound that they result from work outlined by Dr. Thayer; it is under his guidance that I have had the privilege of working. To Dr. George Bond, of the Johns Hopkins Hospital, who has taught me the use of the galvanometric study of the heart, and who has so kindly assisted me in taking the simultaneous tracings, I gladly acknowledge my indebtedness.

In 1907 Einthoven[2] called attention to a wave, obtained on the cardio-phonogram of a normal individual, appearing ·13 seconds (·10 to ·15) after the onset of the second sound. By a method that will be discussed later, he calculated that the sound was below the limits of auditory sensibility. Somewhat earlier, Hirschfelder[6] and Gibson[5] independently called attention to the *h* or *b* wave on venous tracings, and stated that it could be associated with a cardiac sound heard early in diastole. At this time, attracted by the observations of Einthoven, Thayer, who had been describing the so-called third heart sound to his students for many years, undertook a more exact discussion. He associated this "dull shock rather than sound" with the protodiastolic wave of the apex cardiogram, which appears from ·10 to ·18 seconds after the shoulder. He heard the sound in 65 per cent. of young, healthy individuals; and he called attention to various procedures that intensify the sound. This work has been followed up by different investigators working, for the most part, with pathological cases. They all admit the presence of a third sound in normal people, but regard it as being present in a very small percentage of cases. Thus, Gallavardin[1] expresses this general opinion in a recent article, where he refers to the third sound as being heard occasionally in young individuals, but in no way in the frequency suggested by Thayer. To mark out exactly the position of this sound in the cardiac cycle, to associate it with a definite phase in cardiac activity, and to discuss the frequency of occurrence and audibility is the purpose of the present paper.

In order to gain exact information as to this sound and its relation to the events of the cardiac cycle, we have made in each patient studied by us two sets of simultaneous records. In this way the study of cardiac activities from their representations in the various graphic methods is possible. On these records, a common signal and time marker allowed the translation of any occurrence from one curve to another. The several simultaneous apex, venous, and electrocardiographic tracings in each case were immediately

followed by simultaneous venous and electrophonographic curves. In this way synchronous points could be directly compared in the first three, and, by reference to a standard—the venous pulse—their appearance on the electrophonogram could be observed. Apex and venous tracings were obtained by very sensitive tambours on a double-drum kymograph which allowed eight to ten feet of tracing to be taken. The electrocardiograms were obtained by the Edelmann model of the Einthoven instrument. The electrophonograms were obtained by the same instrument, with a tightened fibre, in the manner described by Einthoven,[3] and generally employed in this country.

It is to be remembered that the curves obtained by this method do not show the actual sound waves themselves, but express their translation into an electrical current. Thus, when a sound wave strikes the diaphragm of the microphone, the resistance between the carbon contacts is altered and the amount of current passing through the transformer is changed, thereby producing a current in the secondary or recording circuit. This transformation of energy from one type to another allows the introduction of possible but very slight errors, especially of time, which would have little significance in this discussion. Of much more importance, however, is the introduction of errors of interpretation, especially the tendency to regard the galvanometric vibrations as being synonymous with the sound waves. For instance, one would be tempted to regard the amplitudes of the different phonographic waves as expressing the loudness of the sound that cause the original oscillation of the diaphragm. Here the "free period" of the wire of the galvanometer must be taken into consideration; because for sound waves of equal amplitudes, but of different pitch, the excursion of the string will be very much wider if the frequency in question accords with the frequency for which the particular string vibrates the best. Moreover, the cardiac sounds are not simple harmonics, they are noises made up of tones of varying periods, amplitudes, and phases. So that it is difficult to say that the amplitude is due to one wave, or to the summation of several waves passing through the point of origin at the same time. This also makes the exact knowledge of the original frequency of the sound waves somewhat indefinite, for the vibrations of one wave may be interrupted by those of another, of different period and phase. Recognising these sources of error, it is still possible to obtain a fairly accurate knowledge of cardiac sounds by this method and to obtain ideas as to their relative intensity. For it makes but little difference whether the sounds are of a frequency of 35 or 40, provided they are above the limit of auditory sensibility, and, for the most part, the error in reading the amplitudes will be constant in the same cases.

It is of much greater significance to recollect that not only sound but pressure waves may cause a vibration of the microphone, and thence of the galvanometer; indeed, von Wyss[15] claims that tracings obtained by the Einthoven method represent the vibrations of the chest wall. In so far as these "Erschütterungen" are sounds, fundamentals or overtones, though

they may be of the original cardiac sounds, they are, of course, represented by galvanometric vibrations. But these represent exactly what is desired; they are the resultants which the ordinary stethoscope conveys to the ear. If the proper precautions are taken, it is hard to believe that the simple pressure changes, produced in the receiving system by such chest-wall vibrations, would have much, if any, effect on the diaphragm. In the technique employed in this work, the system is by no means air-tight and the collecting tube is very elastic. That these pressure waves are eliminated, several circumstances suggest. The same electrophonogram results if a half-inch vent is made in the collecting tube; some of the phonographic representations of third heart sound appear without a protodiastolic wave on the apex cardiogram; none of the third heart sound vibrations appear with the beginning of the protodiastolic wave, as they would were they due to pressure changes; there is no continuous or occasional galvanometric vibration throughout systole that should be present were the pressure changes represented. The sensitiveness of the instrument and the proof of its capacity were obtained by the use of tuning forks held at a fixed distance from the receiver. Vibrations of 50, 61, 100, 200, 512 per second are well

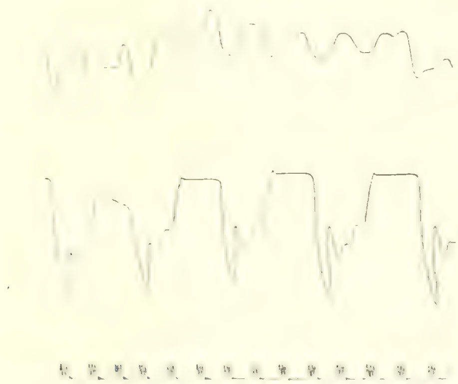


Fig. 1 (redrawn). Simultaneous venous and apex tracings, showing an especially good protodiastolic wave on the apex curve.

recorded; but this instrument fails to respond to vibrations over 1,000 per second. However, as the normal cardiac sounds are generally between 30 and 200 vibrations per second, there is no actual loss by the inability of the instrument to represent high pitched tones.

In this study an effort was made to obtain tracings from absolutely normal boys. To this end, sixteen boys were selected from different schools of Baltimore, with regard only as to their general condition. They were all of average development, of good health, and with no history of cardiac disease. Indeed, more than half were on their school athletic teams. Their ages varied from twelve to fifteen. A careful physical examination showed that thirteen had a third heart sound that was either readily audible, or brought out by methods suggested by Thayer.[11] The auscultatory signs

in two of the other three were questionable ; one boy had no audible third sound. Seven of the boys presented systolic murmurs either at the apex or at the pulmonic area, but otherwise the examination showed nothing remarkable. These observations were checked by either Dr. Thayer or Dr. Bond.

Following this, the different tracings were obtained and numerous measurements tabulated. The cardiac rate at the beginning and end of the tracings was ascertained. The variations in length of the cardiac cycle were noted in the separate cases—the degree of sinus irregularity. These ranged from ·07 in one boy to ·34 seconds in another. It is remarkable that a normal heart beating 76 per minute and, therefore, of an average cardiac revolution of ·79 of a second, could vary from ·67 to 1·01 seconds for the time of individual cycles. Such a fact must be remembered in cardiac measurements. In spite of this difference, there is a great constancy of the time relations in that part of the cardiac cycle which has to do with cardiac activity—systole and diastole as opposed to the "diastasis" of Henderson. Indeed, it is safe to say that practically the whole difference of time, resulting from sinus irregularities, is encompassed in the time of diastasis.

The apex cardiogram has given very constant results in spite of the opinion of most investigators that it is unreliable and of marked variability. That its employment is helpful is brought out by reference to an article by Pachon[8] in 1902. Manoukline's[7] article, in a recent journal, even goes so far as to say that there is a particular type of apex cardiogram for each valvular lesion—an observation which would seem somewhat extreme. It may be that the reason for the constancy in the form of the apex cardiogram in this series lies in the thinness of the chest wall of a young boy, and the ease with which the apex can be localised in them, as opposed to its localisation where there is a thick chest wall or emphysematous lungs in those more advanced in years. Much more importance, however, is attached to the method of taking the tracings. In every case the patient was rotated on the left side, so that the apex was thrown out against the chest, and was extremely well localised, so as to give the curves whose measurements are nearly constant. In this connection it was interesting to observe the great degree of mobility possessed by the hearts of these children. An apex that, with the boy flat on his back, would be in the parasternal line would, in the left lateral position, swing well over to the axilla, even to the mid-axillary line.

The tracings obtained were subjected to different measurements, of which several are important in this paper—the distance from the beginning of the anacrotic wave of the cardiogram to the summit of the protodiastolic wave, and to the foot of the anacrotic wave of the succeeding beat—the distance from the shoulder of the apex tracing to the summit of the protodiastolic wave. These measurements were made on ten sequential beats in all cases where the particular tracing was long enough, otherwise the remaining beats were measured on the next tracing of that case. A comparison of the result sustains the opinion of the constancy of apex tracings taken in the left decubitus. The results obtained are not alone

constant for the individual cases but for the series as well—and this, in spite of pulse rates ranging from 65 to 105, and with the degree of sinus irregularity already described. Whereas the individual ten measurements were recorded, their average will be discussed as the time interval for the particular boy. Thus, in all but two cases, the length of systole, as obtained on the apex tracings, *i.e.*, the period from the beginning of the anacrotic wave to the shoulder of the cardiogram, was either ·30 or ·31 seconds, and in the other two ·32 and ·34. The summit of the protodiastolic wave appeared between ·44 and ·50 after the onset of the anacrotic wave, and, in nearly every case, between ·45 and ·47, averaging ·46 seconds. This same point appeared between ·14 and ·18 after the shoulder, generally ·16, averaging ·16 seconds. This seems very definitely to fix these points; their conformity to the sound tracing will be shown later.

It is recognised that the actual appearance of blood in the aorta is about ·05 of a second later than the onset of ventricular contraction, due to the time necessary to overcome the existing arterial pressure. But true systole begins with or even before the first sign of the ventricular apex curve, and as will be shown, the first sound begins very close to this point. We have, therefore, a definite position from which to measure the protodiastolic wave. In the same way it is evident, from observations made from the comparisons of intra-ventricular and carotid pressure curves, that at the end of actual systole there is a pause of about ·03 of a second with the ventricle in the contracted state, before its subsequent relaxation and the opening of the mitral valve. Again, however, attention is called to the control of the phonograms, where the second sound appears simultaneously with the beginning of relaxation and checks the shoulder of the cardiograms as a definite point. So, therefore, we have the summit of the protodiastolic wave appearing ·46 of a second after the onset of the ventricular cardiogram and ·16 of a second after the shoulder. The time from the protodiastolic wave to the next ventricular rise, while easily computable from the data on hand, is of no importance because it is merely the measurement of the inconstant diastasis.

A translation was then made of the foot of the ventricular rise to the phonogram. This point occurred between ·02 of a second before and ·03 of a second after the beginning of the first sound—generally within ·01 of a second of the first. In six cases the first sound began exactly with the first sign of ventricular rise. The first sound, then, is practically synchronous with the onset of the anacrotic wave of the apex cardiogram. Measurements of the phonograms themselves, obtained from an average of ten sequential beats, give the following results:—the second sound begins between ·30 and ·33 seconds after the onset of the first, averaging ·31 seconds—the third begins between ·45 and ·48 seconds, averaging ·47 seconds after the first sound, and between ·13 and ·18 seconds, generally ·16 seconds after the second sound—averages that correspond exactly to those obtained from apex curve measurements. It is not difficult, therefore, to associate the third sound with the summit of the protodiastolic wave.

In the different articles concerned with the third sound, reference is made to the presence of a rise on the venous pulse between the *v* and *a* waves. It has been found frequently by Hirschfelder,[6] Gibson[5] and Thayer.[11] In fourteen of these sixteen cases the venous tracings were very good ; of these, eight showed, either constantly or occasionally, a small broad wave that appeared ·47 of a second after the *c* wave. Its presence is not necessarily associated with a slow pulse, as some of the slowest heart rates show no *h* wave, while it is present in some of the fastest. Still, in some of the cases with a marked slowing of the pulse, as the boy became accustomed to his surroundings, there is a tendency for a relative exaggeration of the *h* wave in the later tracings. That this wave appears at about the same time as the protodiastolic wave at the apex, suggests a common origin ; its inconstancy, and the circumstance that it is in no way proportional to the size of the protodiastolic wave is, however, not remarkable when one considers that the third sound and the protodiastolic shock at the apex are probably left ventricular phenomena, while the *h* wave is probably related directly to events on the right side of the heart.

There are various procedures, suggested for the most part by Thayer,[11] which tend to accentuate the third sound. In some boys they bring out sounds that otherwise would have been regarded as absent. The prone position is essential. Joachim and Weiss,[13] with their " soap bubble " phonoscope, generally examine their patients in the upright position, and as a result they say " dass von einem ' dritten Herzton ' wie ihn Einthoven auf einigen seiner Kurben dargestellt hat, auf unseren Kurben *nie* etwas zu sehen war." The left lateral position will often bring out a sound inaudible with the boy on his back. The sound is best heard immediately after reclining, best heard during inspiration or early expiration, and is accentuated by raising the patient's arms and legs. Another useful procedure is to let the patient take some moderate exercise, when on lying down a beautiful third sound may be developed. These influences were all studied during physical examinations, and after such procedures the records showed increased amplitude of the waves, corresponding to the third sound. Exercise seemed particularly helpful if the heart did not become too rapid. In two of three adults with a very slight third sound, in the other suggested positions, a little preliminary exercise brought out, to the ear and on the phonogram, a very clear third sound with the patient lying on his back.

The frequency of the third sound in these cases certainly supports Thayer's view ; it was definitely represented on the phonograms of all the boys. This leads to a discussion of the sensibility of the ear to this sound, and a review of the methods of determination of the intensity of sound. In the first place, the sensibility to sound is a subjective quality ; it is a sensation and not a physical quality ; and, therefore, we have no unit for measuring it. We do know, however, that sounds to be audible must lie within certain frequencies, between 30 and 20,000 per second ; and, again, of two tones of equal pitch, their loudness varies with their amplitudes.

Further, a measure of the intensity of sound is permissible if we multiply the square of the amplitude by the square of the frequency. But this emphasises the need of caution in regarding the amplitudes of the records as representing the amplitudes of the sound vibrations. Consider in this connection the fact that the third sound wave is sometimes represented by a single hump above or below the line, with a very slight corresponding swing in the opposite direction. The sound wave causes the diaphragm of the microphone to buckle in, thus causing the differences of contact, through the carbon particles, and the swing of the galvanometer results. This should be followed by a rebound of the diaphragm, in turn causing a second change in potential, and a swing of the galvanometer of an equal amount, but in the opposite sense. The absence, or great decrease, of the second swing could only be due to damping of the sound. It might be suggested that the "hump" was due to a simple pressure wave, where the pressure, being maintained, prevented the diaphragm from bounding back to normal. But this is not the case, for after the rise of the protodiastolic wave, there is an immediate fall. The pressure, then, is not maintained although the sound recorder does not swing below the line. Furthermore, the fall and the rise of the protodiastolic wave occupy nearly the same interval of time – there is no gradual reduction of pressure. Recognising this damping, which is so great as to prevent a sound wave from being entirely represented, is it not unwise to regard even the first excursion as being a full measure of the amplitude ? The recorded amplitude may be but a part of the true swing.

Einthoven[2] states that the third sound is made up of a single vibration. In many of these boys the phonograms show two complete waves and in one instance there were three vibrations. While recognising the difficulty of forming final conclusions, we may compare the phonographic appearance of the first, second, and third sounds as they appear on the same tracings, with the idea that, under similar conditions, there would be a tendency for the damping to be a constant factor of error, and that, by averaging, other errors might be eliminated for the most part. The length or time interval of the phonographic representation of the third sound ranged from ·02 to ·09 seconds. The frequency, however, was fairly constant—about 33 per second—varying from 30 to 50. In the same way the duration of the first sound was, on an average, ·14 seconds, with a wave frequency of about 40 ; and the second sound averaged ·08 seconds and was of a pitch represented by 50 vibrations per second. These figures vary somewhat from those of Einthoven, who regards the frequency of the first and second sounds as about 100, and that of the third as 50 ; but they are substantiated by Joachim and Weiss, for the first and second sounds, who employ an entirely different method of registering sound waves. The pitch of all three sounds is not very different, ranging from 33 to 50 vibrations per second.

Having determined the apparent frequency, the amplitude is obtained by direct measurements. The figures vary and can be ascertained for the different cases from the tables. In one case, for instance, the measured

amplitude of the three sounds is 40, 28, and 8. The relative intensities, therefore, would be the square of the frequency times by the square of the amplitude; or, for the first sound, 2,560,000; 1,960,000 for the second sound; and 69,696 for the third; or in a simple ratio—37 : 28 : 1. In the second case the relative intensity, in the same way, would be 10 : 70 : 1. This is opposed to Einthoven's calculation that the third sound was 196 times weaker than the first or second. Einthoven further claims that the sensibility of the ear for these different sounds depends on the pitch. He states that, with equal intensities, his third sound of 50 vibrations would be 100 times less readily heard than that of the first sound of 100 vibrations. This he bases on the tests of sensibility conducted by Max Wien,[14] who, with a series of telephones, maps out the intensities of sounds of different wave lengths and tests their relative effect on his own ear. Such work confirms the view that sounds of certain frequencies are better heard than those of another pitch. But his conclusions, where he exactly tabulates sounds of every pitch, are not agreed to by Zwaardemaker and Quix,[16] who call attention to errors in technique whereby bone conduction is involved in the calculations that Wien bases on air conduction alone. Further, there is a disagreement as to calculation; and again, as the test depended on the sensibility of Wien's ears, no definite conclusions can be drawn as to sensibility in general. The result of Einthoven's calculation is that the third sound is not audible. Possible sources are here suggested for the incorrect conclusion, for the third sound is readily heard in many cases.

In one of his articles, Thayer[11] recalls the suggestion of Brauer[1] that the protodiastolic wave and the third sound may represent an active muscular phase of diastole. Any muscular activity necessitating stimulation and chemical changes on the part of the heart must, of necessity, be represented on the electrocardiogram. The only wave that could in any way be connected with this early diastolic movement is the T wave, as none of the electrocardiograms in this series showed a U wave. Measurements show that the beginning of the protodiastolic wave is between ·10 and ·15 after the onset of the T wave—the time to the summit of the protodiastolic wave is, of course, even longer. But the ventricular or auricular waves on the electrocardiogram begin only about ·03 or ·05 seconds before their corresponding rises on the apex tracing. So that the protodiastolic wave and third sound cannot be associated with actual cardiac muscular action.

The third heart sound, then, occurs at the end of diastole, just at the completion of the sudden rush of blood from auricles to ventricles, the end of diastole. It is a sound localised at the apex, and only rarely heard over the right ventricle. This fact and, as has been pointed out, the inconstancy and small size of its representation on the venous tracing rather associate it with the left side of the heart. It is intensified by increased venous and intracardiac pressure, as occurs if the extremities are supported, after exercise, during inspiration. Its actual cause must be problematical, but the views of Hirschfelder,[6] Gibson,[5] and Thayer[11] are generally accepted—

that it has origin in the vibration of the auriculo-ventricular valves—caused by their sudden floating up as the ventricle is filled.

The association of the sound with pathological cases is not taken up here, although its analogue in the protodiastolic gallop must be suggested. The purpose of this paper will have been met if it proves that a third sound is audible in many people, that it is very commonly found in children, and that it occupies a definite position in the cardiac cycle marked by the summit of the protodiastolic wave of the apex cardiogram.

Summary.

(1.) The third sound was definitely audible in thirteen of sixteen normal boys, and was represented on the phonograms of all. It is accentuated by different manœuvres.

(2.) Einthoven's calculations, whereby the third sound is regarded as being below the limits of audibility, are questioned and comparisons are made which tend to show that the third sound is of nearly the same intensity as the first or second.

(3.) Comparative measurements of electrophonograms and apex tracings show that the third sound occurs at the summit of the protodiastolic wave of the apex cardiogram—·47 seconds after the onset of the anacrotic limb, and ·16 seconds after the shoulder.

(4.) The association of the third sound with the protodiastolic gallop is suggested.

(5.) The constancy of systole and diastole and the variability of diastasis is noted.

(6.) The use of the apex cardiogram is emphasised.

Comparison of the electrophonograms and apex tracings.*

Name.	Phonogram.			Apex Cardiogram.		
	Length of Cycle.	1st to 3rd.	2nd to 3rd.	Length of Cycle.	Onset of Ventricular Rise to Summit of Protodiastolic	Shoulder of Cardiogram to Summit of Protodiastolic
B.R.	·72 sec.	·49 sec.	·18 sec.	·81 sec.	·47 sec.	·17 sec.
K.S.	·91 ,,	·49 ,,	·16 ,,	Not read	Not read	Not read
A.L.	·76 ,,	·47 ,,	·15 ,,	·77 sec.	·46 sec.	·15 sec.
N.S.	·67 ,,	·47 ,,	·16 ,,	·63 ,,	·45 ,,	·14 ,,
C.P.	·86 ,,	·47 ,,	·16 ,,	·74 ,,	·46 ,,	·15 ,,
J.S.	·72 ,,	·48 ,,	·17 ,,	·75 ,,	·48 ,,	·18 ,,
E.G.	·69 ,,	·46 ,,	·15 ,,	·68 ,,	·46 ,,	·16 ,,
E.W.	·73 ,,	·46 ,,	·15 ,,	Not read	Not read	Not read
L.G.	·70 ,,	·47 ,,	·16 ,,	·70 sec.	·45 sec.	·14 sec.
J.B.	·79 ,,	·48 ,,	·17 ,,	·75 ,,	·47 ,,	·16 ,,
C.C.	·79 ,,	·48 ,,	·15 ,,	·80 ,,	·46 ,,	·16 ,,
B.L.	·91 ,,	·48 ,,	·15 ,,	·95 ,,	·50 ,,	·16 ,,
R.T.	·69 ,,	·45 ,,	·15 ,,	Not read	Not read	Not read
N.B.	·70 ,,	·46 ,,	·15 ,,	·71 sec.	·47 sec.	·16 sec.
W.N.	·64 ,,	·45 ,,	·15 ,,	·58 ,,	·44 ,,	·17 ,,
I.R.	·74 ,,	·46 ,,	·14 ,,	·64 ,,	·46 ,,	·16 ,,

* These measurements represent the average of ten sequential beats.

TABLE SHOWING A COMPARISON OF THE ELECTROPHONOGRAPHIC REPRESENTATION OF 1ST, 2ND AND 3RD SOUNDS.

Name.	1st Sound.			2nd Sound.			3rd Sound.		
	Duration.	No. of Waves.	Amplitude.	Duration.	No. of Waves.	Amplitude.	Duration.	No. of Waves.	Amplitude.
E.W.	·15	5	16	·08	3	12	·03	1	5
L.G.	·13	6	18	·09	3	16	·02	1	5
J.B.	·12	5	18	·08	3	26	·03	1	6
C.P.	·16	6	18	·12	4	38	·03	1	7
J.S.	·16	4	13	·08	3	5	·04	1	3
E.G.	·13	4	24	·12	3	12	·03	1	4
C.C.	·16	5	12	·08	5	11	·02	1	5
B.L.	·16	7	26	·16	3	20	·06	2	5
R.T.	·14	6	16	·06	4	24	·06	2	4
N.B.	·17	6	18	·06	4	12	·04	2	5
W.N.	·13	6	14	·08	5	12	·03	1	4
I.R.	·15	5	40	·06	3	28	·03	2	8
B.R.	·18	7	18	·04	9	6	·07	2	6
K.S.	·11	7	14	·05	3	14	·05	2	4
A.L.	·12	5	18	·08	4	26	·09	3	7
N.S.	·13	6	30	·06	5	16	·04	2	4

BIBLIOGRAPHY.

1. BRAUER. In Verhandl. d. Kong. f. inn. Med., Wiesbaden, 1904, XXI, 187.
2. EINTHOVEN. "Ein dritter Herzton." Archiv. f. d. ges. Physiol., 1907, CXX, 31.
3. EINTHOVEN. "Die Registrirung der menschlichen Herztöne mittels des Saitengalvanometers." Archiv. f. d. ges. Physiol., 1907, CXVII, 461.
4. GALLAVARDIN. "Bruit de Dédoublement Mitral et Troisième Bruit." Archiv. d. Malad. du Cœur, 1912, V, 776.
5. GIBSON. "The significance of a hitherto undescribed Wave in the Jugular Pulse." Lancet, 1907, II, 1380.
6. HIRSCHFLEDER. "Some Variations in the Form of the Venous Pulse." The Johns Hopkins Hosp., Bull, 1907, XVIII, 265.
7. MANOUKLINEE. "Le Cardiogramme en Décubitus Lateral Gauche dans les Affections Valvulaires du Cœur." Archiv. d. Malad. du Cœur, 1914, VII, 107.
8. PACHON. "Contributions à la Technique Cardiographique chez l'Homme." Soc. de Biol., 1902, LIV, 884.
9. POTAIN. "Clinique Médicale de la Charité," Paris, 1894.
10. THAYER AND MACCALLUM. "Experimental Studies of Cardiac Murmurs." Amer. Journ. med. Sci., 1907, CXXXIII, 249.
11. THAYER. "On the Early Diastolic Sound." Bost. med. and surg. Journ., 1908, CLVIII, 713.
12. THAYER. "Further Observations on the Third Heart Sound." Archiv. of intern. Med., 1909, IV, 297.
13. WEISS AND JOACHIM. "Registrierung und Reproduktion menschlicher Herztöne und Herzgeräusche." Archiv. f. d. ges. Physiol., 1908, CXXIII, 341.
14. WIEN. "Ueber die Empfindlichkeit des Menschlichen Ohres fur Töne verschiedener Höhe." Archiv. f. d. ges. Physiol., 1903, XCVII, 1.
15. VON WYSS. "Aufzeichnung von Herztönen mit dem Einthoven'schen Saitengalvanometer und Untersuchungen über Galopprhythmus." Deutsch. Archiv. f. klin. Med., 1911, CI, 1.
16. ZWAARDEMAKER AND QUIX. "Ueber die Empfindlichkeit des menschlichen Ohres für Töne verschiedener Höhe." Archiv. fur Anat. u. Physiol., 1904 (Phys. Abth.), 25.

Electrophonograms showing how different procedures may bring out a third sound otherwise inaudible.

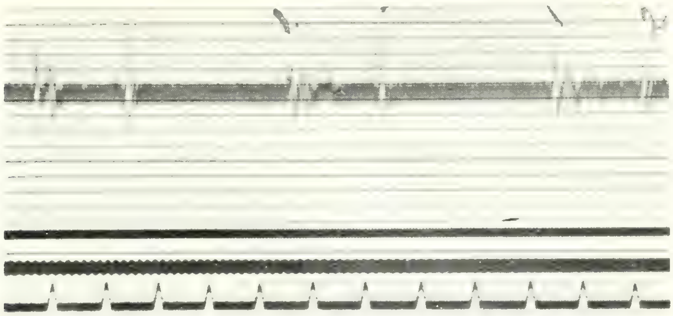


Fig. 2. Taken with patient lying quietly on his back. Shows a first and second sound.

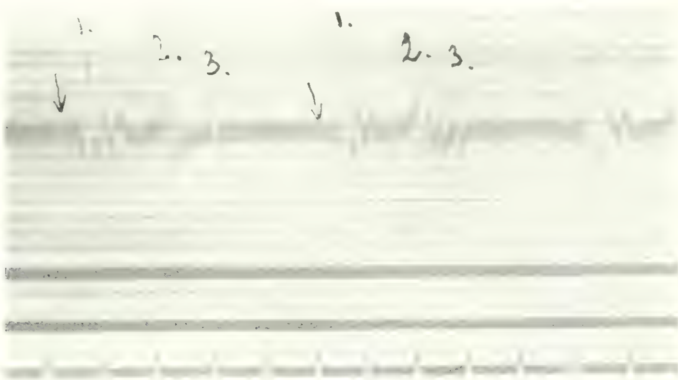


Fig. 3. Same patient rotated on his left side. Showing a well marked third and an occasional presystolic sound.

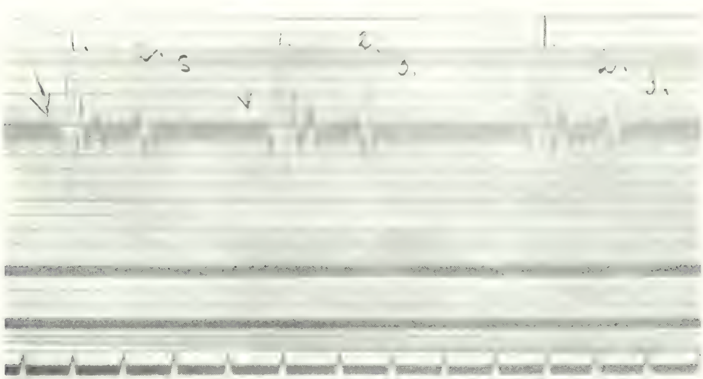


Fig. 4. Same patient lying quietly on back with limbs supported in the air. Showing a well marked third and an occasional presystolic sound.

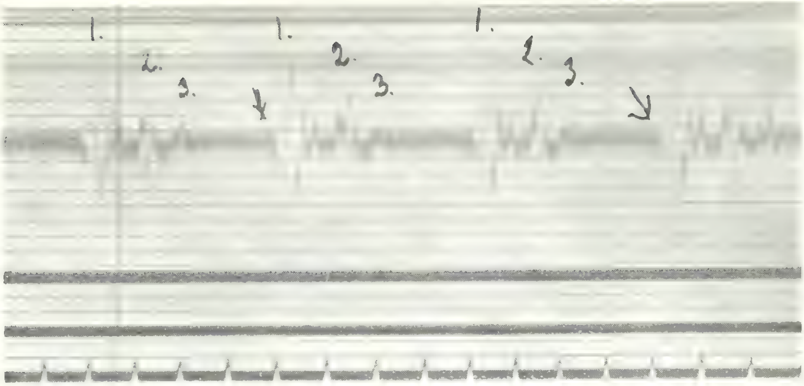


Fig. 5. Same patient lying quietly on back after moderate exercise. Showing a definite third and presystolic sound.

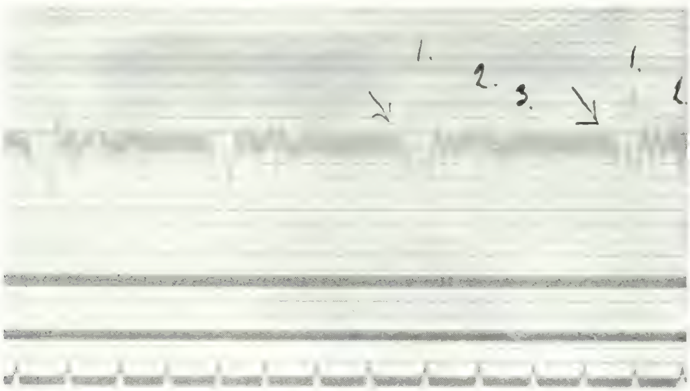


Fig. 6 Same as Fig. 4. After exercise. Showing an especially well marked presystolic sound.

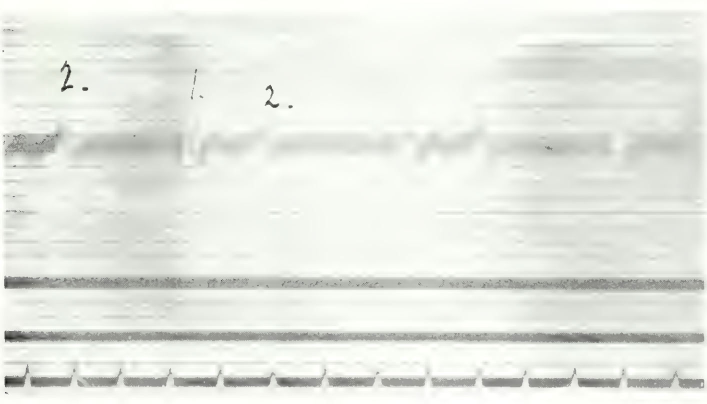


Fig. 7. Same patient after lying quietly on back for five minutes to show disappearance of third sound.

Electrophonograms of L. G. with different strengths of primary current.

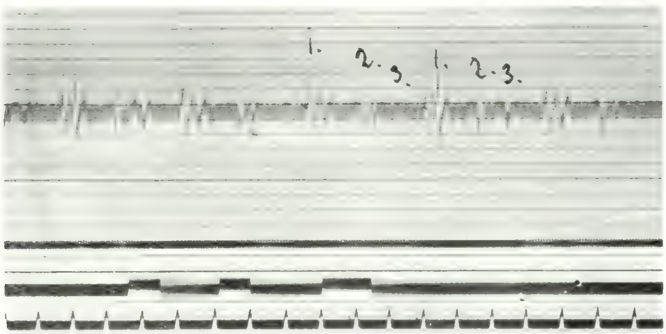


Fig. 8. Shows a definite third sound. Patient lying on back.

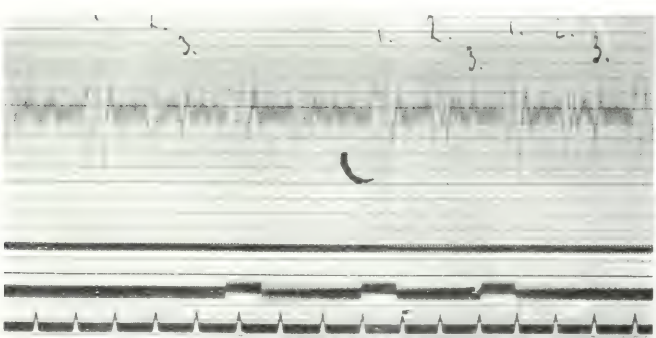


Fig. 9. Shows a definite third sound. Patient lying on back.

DIRECT PULSATION RECORDS: A NEW PHOTOGRAPHIC METHOD.

By JOHN PARKINSON.

(*From the Cardiac Department of the London Hospital.*)

Pulsation is usually recorded by means of a receiver connected by a rubber tube with a recording tambour. The most convenient form of such apparatus for clinical use is the Mackenzie ink polygraph. Since the introduction of the electrocardiograph it has been found an advantage in certain cases to combine a polygraphic with an electrocardiographic tracing. For this purpose the levers of tambour systems may be inserted in the ray of light from the electrocardiograph. In this way a triple record is obtained on the moving photographic plate or film of the camera. The value of such a record is often great. In cases of auriculo-ventricular tachycardia, or even in some cases of auricular tachycardia, it may be impossible to identify the auricular complex with certainty in the electrocardiogram, and the same statement applies to certain instances of solitary extrasystole and to certain examples of heart-block. In such cases the position of the wave in a coincident record of the venous pulse may yield valuable evidence as to the time of auricular contraction. If a radial tracing is also included the whole record is brought into relation with the common clinical method of feeling the pulse.

In 1913, while taking a triple record of electrocardiogram with jugular and radial tracings from a case of heart-block, we found the venous impulse in the neck so large and forcible that the tambour connected with the neck proved scarcely adequate for its representation. It then occurred to us that if the neck was placed directly in the beam of light from the electrocardiograph, a record of the pulsation would be directly obtained in magnified form on the moving plate of the camera, much as the movements of a capillary electrometer are recorded photographically.

Method.

An electrocardiograph is used in which the camera stands on a separate table, and is separated from the rest of the apparatus by 80 c.m. or more. The base of a dental chair is inserted in this space and a simple wooden seat without a back is fixed upon it. The patient when seated upon this chair can be raised, lowered, or turned to left or right at will by means of the foot levers. The clothing is removed from about the neck and shoulders. The site of maximum visible pulsation is noted with the aid of a top light. The patient is then turned and elevated or lowered until the edge of the shadow

of this maximum pulsation is moving to and fro across a portion of the horizontal slit of the camera. The most suitable position appears to be that in which the patient is looking towards a point on the left of the camera and with his back to the switch-board of the Cambridge instrument. In this way the right antero-lateral portion of the neck intercepts part of the beam of light and gives the pulsating shadow (Fig. 1 and 2). The nearer the patient sits to the camera the sharper is the edge of the shadow, and the further he sits from the camera the larger is the excursion.

When the pulsating shadow is clearly seen, the prepared electrodes are connected with the patient's limbs, with the least possible change in his position, for this has already been chosen to show the maximum pulsation in the neck. It is not impossible to place immersion electrodes in the necessary position without undue disturbance, and body vibrations are usually less when they are used.

When the shadow of the pulsation is clearly seen the string of the electrocardiograph is standardised in the usual way and brought to a suitable distance from the edge of the pulsating shadow upon the slit of the camera. In some cases the best results are obtained by taking the record while the patient's breath is held ; in others this causes disappearance of the pulsation.

The pulsation of the apex beat, or a superficial artery or vein, or an aneurysm may be recorded in a similar fashion (Fig. 5, 8).

Difficulties often arise in applying this method and to many patients it is inapplicable. Pulsation of the neck, though prominent while the patient is reclining, may be invisible when he is sitting. In such a case it is unlikely that a satisfactory result will be gained. If the pulsation is only reduced by the sitting posture, the lower limbs and abdomen may be tightly bandaged so as to increase the volume of blood in the cervical veins. If this fails, a piece of plasticine may be placed upon the site of pulsation and so arranged as to throw the shadow, though this is of less utility than might be expected. When the position of the patient is an uncomfortable one the resulting body-vibrations may deform the electrocardiogram. They can be minimised by inviting the patient to relax himself and by taking every precaution to make him as comfortable as possible. An adjustable head rest was tried, but proved to be of little value.

Application.

It is not suggested that this method can supersede the graphic methods at present in use. It is proposed as an additional means of recording pulsation, especially where it is desired to exclude instrumental delay or fling. Direct pulsation curves will also remind the student of the relation between electrocardiographic complexes and the movement of blood in the vessels of the neck, both as seen at the bedside and as recorded on the polygraph.

Visual examination of pulsation in the neck is unfortunately of little value and serious errors in diagnosis are likely to be made if reliance is placed

upon it. An example is given where auricular flutter was simulated in a case with a rapid normal rhythm (Fig. 9). In paroxysmal tachycardia the pulsation has often been described as of carotid origin when it was really venous. Interpretation of the direct records given in this paper would be difficult without the accompanying electrocardiogram ; interpretation of pulsation merely by looking at the neck is still more difficult.

It is possible that the direct method may be found applicable in certain physiological experiments where it is necessary to record rapid movements. The contracting tissue could be arranged in a beam of light so that the edge of its shadow crossed the slit of a camera containing a moving photographic plate.

Two figures are appended illustrating the method (Fig. 1, 2), and eight exemplifying the direct records obtained (Fig. 3-10). In all these figures a movement of pulsation is toward the centre of the figure ; if the curve is on top the movement is downward ; if the curve is at the bottom the movement is upward.

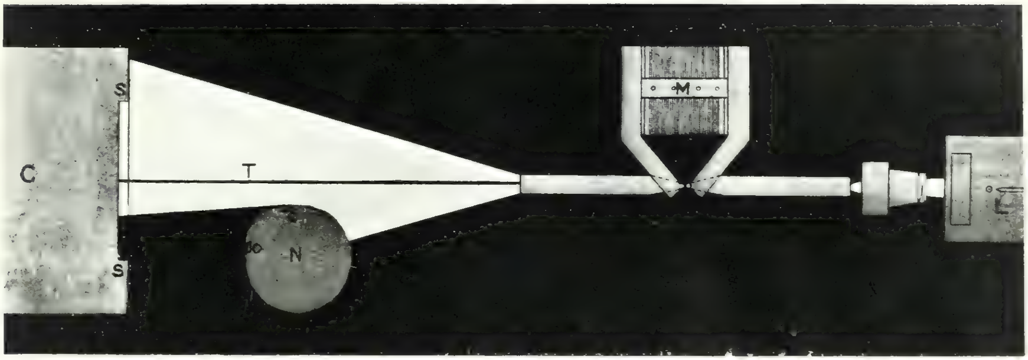


Fig. 1. Plan of apparatus. L, lamp. M, magnet. T, shadow of thread. C, camera. S.S, camera slit. N, Neck.

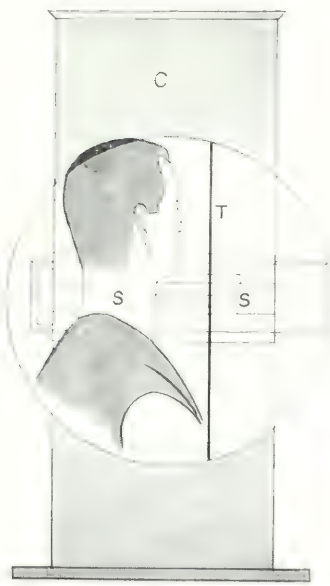


Fig. 2 The same in elevation. C, camera. T, shadow of thread. S.S, camera slit

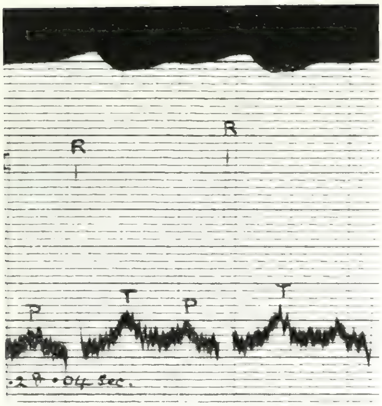


Fig. 3.

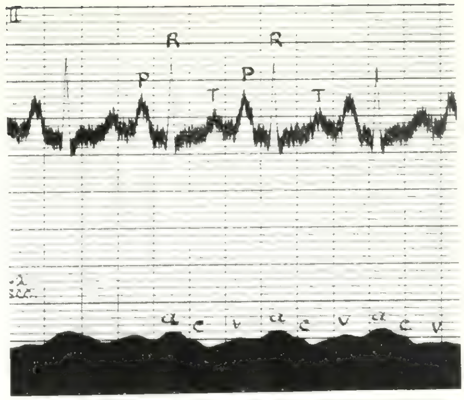


Fig. 4.

Fig. 3. *Carotid pulsation.* From a patient with aortic incompetence. It shows the commencement of carotid pulsation 0·1 sec. after *R*. In two other records, taken from normal men, this interval was also 0·1 sec. The dicrotic notch is visible.

Fig. 4. *Jugulo-carotid pulsation* (normal). The three waves, *a*, *c*, and *v*, are shown.

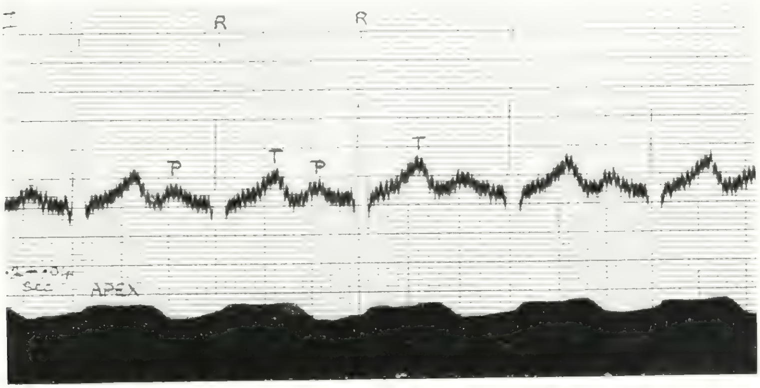


Fig. 5. *Apex beat.* A direct record obtained by allowing the patient to stand so that the shadow of the apex beat fell upon the slit of the camera. The rise occurs less than ·04 sec after *R*. A depression is seen on the summit.

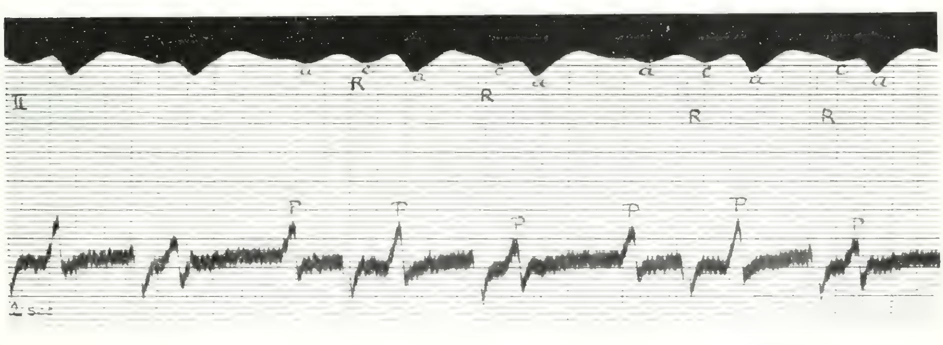


Fig. 6. *Heart-block* (3 : 2). The largest waves are produced when auricular contraction coincides with ventricular systole.

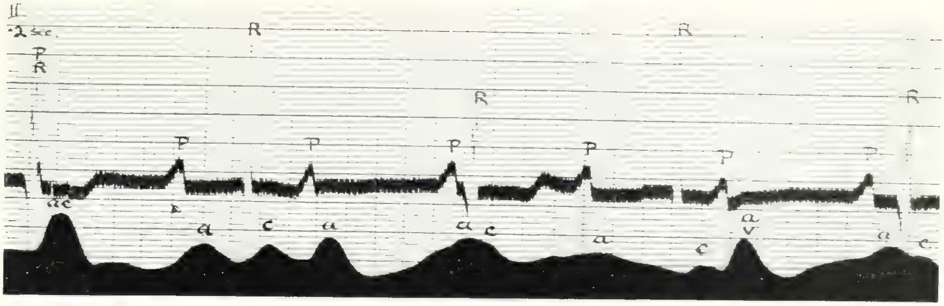


Fig. 7. *Complete heart-block.* The highest wave is produced when P falls with R, and high ones whenever P falls within the R T period.

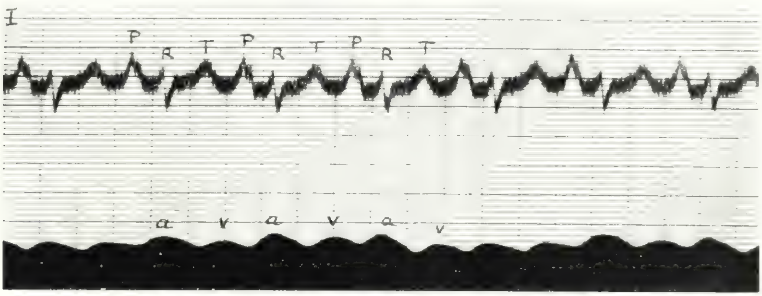


Fig. 9. *Pulsation simulating auricular flutter.* This record was obtained from a patient diagnosed as auricular flutter on account of the rapid regular pulsation in the neck and a regular pulse of 130 per minute. The electrocardiogram showed a normal rhythm and the pulsation, illustrated in this figure, was due to a succession of a v waves. (Simple tachycardia.)

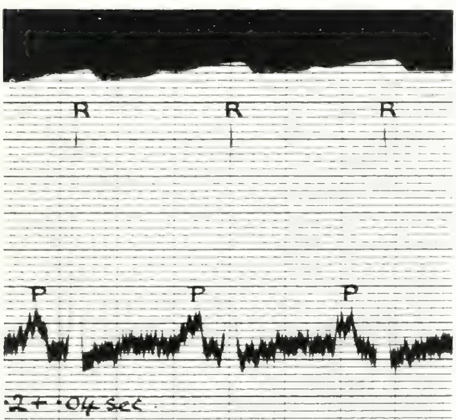


Fig. 8.

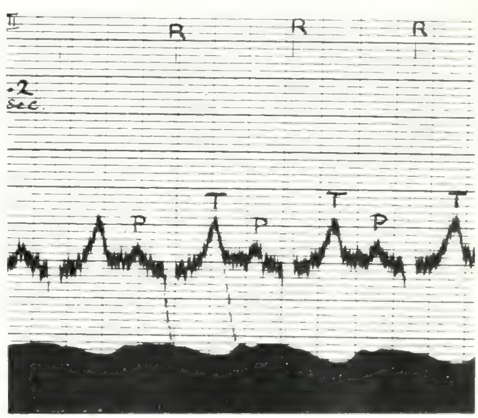


Fig. 10.

Fig. 8. *Thoracic aneurysm.* Pulsation directly from the second right intercostal space two inches from the middle line and due to an aneurysm. The wave begins ·08 sec. after R, rather earlier than the carotid wave would appear. The dicrotic notch is visible.

Fig. 10. *Systolic tug of adherent pericardium.* A figure obtained by allowing the patient to stand in the beam of light so that the edge of the shadow was cast by the left lower ribs. There is a small unexplained notch at the beginning and at the end of the systolic depression.

A CASE OF VENTRICULAR FIBRILLATION.

By R. H. HALSEY.

(*New York.*)

In an earlier volume of *Heart* a case was reported by Hoffman[1] in which a period of fibrillation of the ventricle was reported to have occurred at the end of a paroxysm of tachycardia. The deflections as registered in the record resemble very closely a group of ventricular premature contractions arising from varying foci.

In two records obtained by Robinson[2] of dying hearts, a short period of ventricular fibrillation seems to occur as a terminal phenomenon in the activity of the heart.

In the case now reported there was a rapid change in the mechanism. At first a normal sequence became slow, then delayed conductivity appeared; ventricular fibrillation appeared abruptly and caused death.

History. K. DeB., age 30, admitted February the 4th, 1913, with broncho-pneumonia of both lower lobes. During the previous four years she had had shortness of breath on exertion, and in May, 1912, a labour was induced because of the belief she could not go to term without great risk of losing her life. Examination showed the apex of the heart to be in the 5th space, 13 cm. to the left, while the right border was 2·5 cm. from the midline. On admission the heart was beating regularly at the rate of 120 per minute, and the heart sounds were feeble; the second aortic was louder than the second pulmonic sound. There were no murmurs. The disease progressed favourably until the 11th of February, one week after admission, when there was a sudden increase in the rate of the heart, in dyspnœa, and the facies indicated that death was imminent. At 2:50 p.m. electrocardiograms of all three leads were obtained. At 2:55 she had ceased breathing and the convulsive gasp of death had occurred, but the galvanometer continued to register deflections until 3:1, when the recorder registered no movement.

Curves. The curves were taken one after the other in quick succession and are described in this order. In Fig. 1 (Lead *I*) the frequency of the heart is 75. The duration of the diastole varies from 0·2 sec. to less than 0·1 sec., and is non-rhythmic. The up-stroke of *P* is quicker than the

down-stroke. The conduction time is within the normal limits of 0·2 sec.. The *Q R S* complex is downward and requires over a 0·1 sec. for its completion, the apex being serrated. *T* is upward in its direction and of considerable excursion.

In Fig. 2 (Lead *II*) the frequency of the heart is 80. There are the same variations in the duration of the diastole. *P* is somewhat over 0·1 sec. in its duration, with a deflection of some 5 mm. to 6 mm. extent. The up-stroke of *P* in some complexes is quick and in others slow, while the down-stroke varies in its speed and extent. Conduction time about 0·2 sec.. In the *Q R S* complex, the first deflection is upward and is followed by an equal movement below the line. These deflections occupy about 0·15 sec.. *T* is upright and varies in amplitude, though it retains the same general form from complex to complex.

In Fig. 3 (Lead *III*) the frequency of the heart is 90. There is some variation in the length of the diastolic period ; *P* consists of a short, sharp up-stroke with a spilt apex, a slow down-stroke. The conduction time is 0·2 sec.. The *Q R S* complex is in the main an upright deflection which requires somewhat over 0·1 sec. for its completion. *T* is directed downward and is variable in amplitude. The length of the ventricular complex is 0·5 sec..

In Fig. 4 the record shows the frequency of the heart to be 80, and there has been a slight change in the form of the complexes. The *P-R* interval has grown from 0·25 to 0·30 sec.. *S* and *T* have become greater in amplitude, while *R* has diminished. The duration of the whole contraction requires about 0·45 sec..

The next record (Fig. 5) shows the frequency of contraction of the heart to have dropped to 45, while association of auricle and ventricle is still present. The conduction time is 0·40 sec. ; double the time in the earlier record. The *Q R S* complex has now altered considerably. The patient was still breathing at this time. The duration of the whole ventricular complex is lengthened and requires 0·6 sec..

During the very brief interval between the taking of Fig. 5 and 6, convulsive gasps and a slow contraction of the skeletal muscles occurred. In Fig. 6 the change is remarkable, and the frequency of the ventricle has increased to 63 per minute. At one point (*P*) there is a complex, the last one to be observed, resembling in every way the *P* complex of No. 5 ; it is followed in 0·2 sec. by a quick up-stroke of 12 mm. succeeded by a very slow and great fall below the base line, and a very slow recovery to the base line, the whole phase requiring about 0·8 sec. for its completion.

The remaining complexes vary in their detailed form, but are similar in general outline.

In Fig. 7 there are no evidences of co-ordinate ventricular contraction, an irregular movement of the string, characteristic of ventricular fibrillation, is seen. The remaining records are similar ; at the end of Fig. 13 all movement ceased permanently.

Discussion.

The records published form an almost complete electrocardiographic record of the heart beat during the last movements of the patient's life. Though death was expected, yet its actual advent was much earlier than had been anticipated; the transition from life to death was abrupt. The warning of change is to be found in the lengthened conduction interval and in the changed ventricular complex of Fig. 5. That fibrillation of the ventricles was not the immediate cause of death is clear from Fig. 6, taken when the usual signs of life were in abeyance; the heart was profoundly affected, and the patient past all possible hope of recovery before fibrillation ensued. This fibrillation, of whose occurrence the records bring convincing evidence, appears to have been the terminal event in the heart itself. The whole series of changes is similar to what may be observed sometimes at the end of an experiment in poisoned animals, or will vary as a result of asphyxiation. We may regard the changes as a result of the terminal breakdown of metabolism, or the final reaction of the heart to foreign substances accumulating in the blood stream.

SUMMARY.

This report contains a description of the electrocardiographic curves, taken almost continuously from a patient over the time of death from broncho-pneumonia. The final event was ventricular fibrillation.

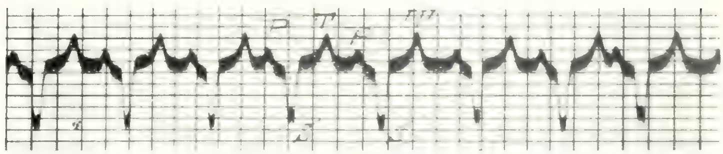
My thanks are due to Dr. Quintard, Director of Medicine at the New York Post-graduate Hospital Medical School, where the observations were made, for permission to publish them.

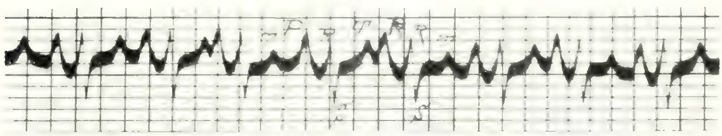
BIBLIOGRAPHY.

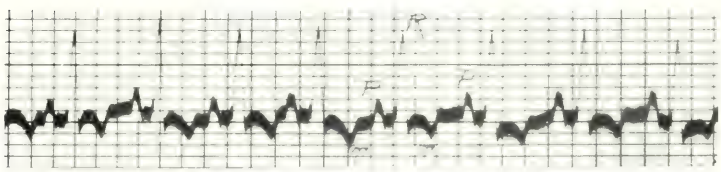
[1] Hoffman, A. Heart, 1911-1912, iii, 213.

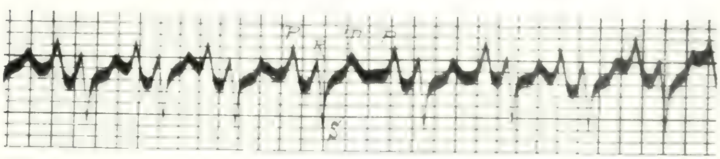
[2] Robinson, G. C. Journ. Exper. Med., 1912, xvi, 291.

In the electrocardiograms the string is calibrated so that 1 cm. of deflection equals 10^{-4} volts. The vertical lines occur every 0·2 seconds.









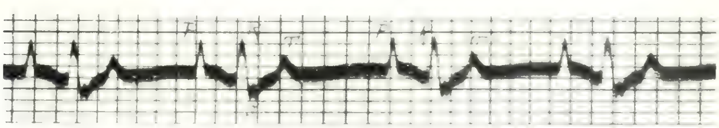


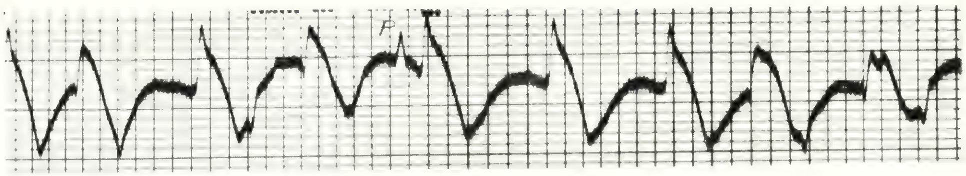
Fig. 1. Lead *I* taken at 2.50 p.m.

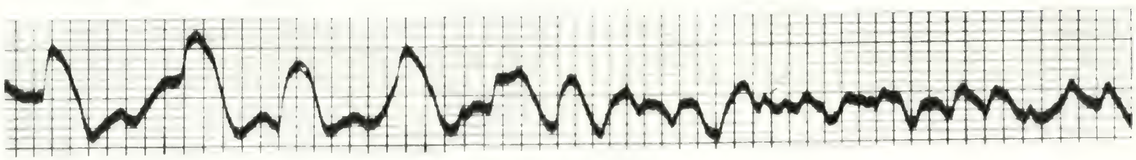
Fig. 2. Lead *II*.

Fig. 3. Lead *III*. Note the form of ventricular complex which with Fig. 1 seems to indicate a block of the left branch of the *A-V* bundle.

Fig. 4. This and subsequent records are from Lead *II*.

Fig. 5. The rate is halved and the *P-R* time doubled (0·4 sec.).





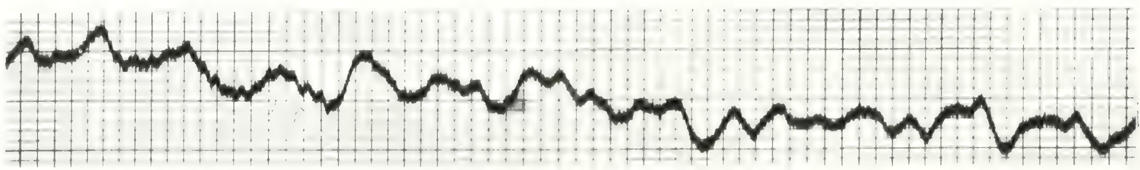


Fig. 6. Last auricular P complex occurring during the slow deliberate ventricular contractions.

Fig. 7-9. These figures depict fibrillation of the ventricles.

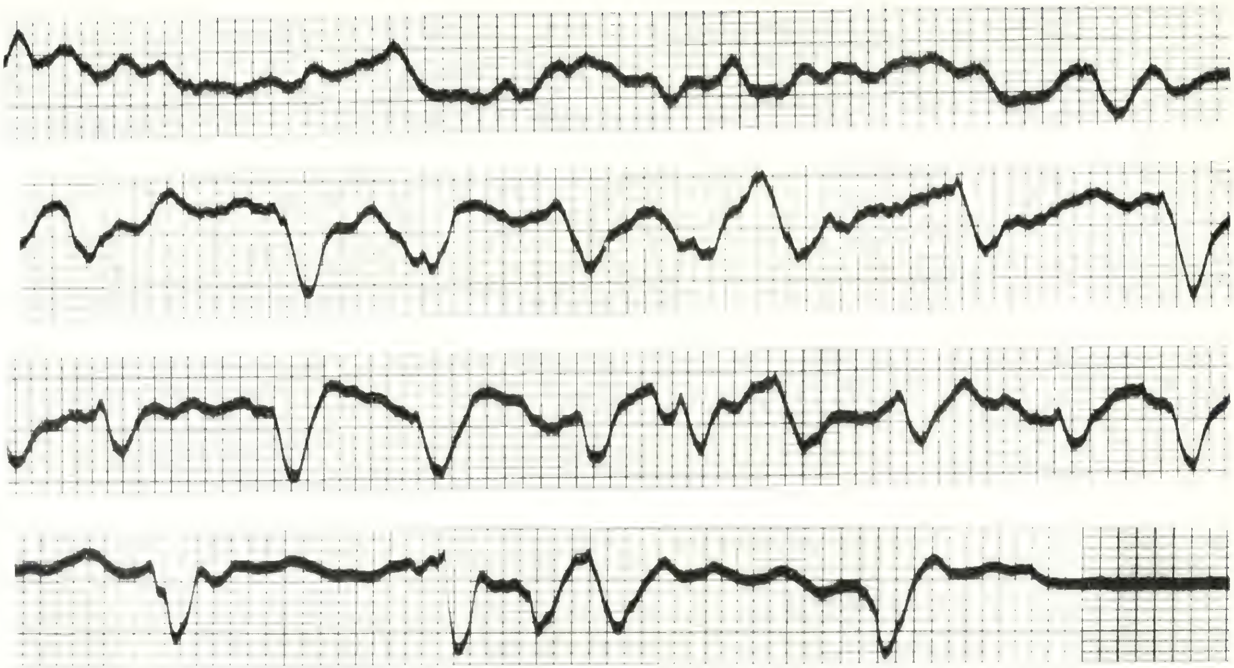


Fig. 10-13. These figures depict fibrillation of the ventricles.

OBSERVATION UPON CHEYNE-STOKES BREATHING.

By F. T. FULTON.

(*Providence.*)

Of late years careful study has revealed two distinct types of Cheyne-Stokes respiration which differ very materially from each other, and it has been shown that the determination of the type may be a valuable aid in diagnosis.

The first important work done which had a definite bearing on the differentiation of the types was that by Cushing.[1] His work was at first experimental and had as its primary object the demonstration of the relation between abnormal intracranial tension and arterial blood pressure.

Cushing showed that if the intracranial pressure be raised experimentally to a point higher than the arterial pressure there is in consequence an anæmia of the brain which contributes to a stimulation of the vaso-constrictor centre and brings about a compensatory rise of the blood pressure to a point higher than the intracranial. In this work he observed that at some fixed point of high intracranial pressure Traube-Hering waves of blood pressure would appear. The average level of these waves of blood pressure was not materially higher than the intracranial tension, but during one phase it would be higher and during the other lower, thus producing a condition in which a period of brain anæmia alternated with one of established circulation. These waves were associated with a periodic breathing simulating the Cheyne-Stokes type. The rise of blood pressure which re-established the cerebral circulation was associated with the period of hyperpnœa, and also with an increase of pulse rate; the fall of pressure with the resulting brain anæmia was associated with the period of apnœa and a slowing of the pulse. Clinical observations showed the same relationship between the periods of hyperpnœa and apnœa and the blood pressure and pulse rate in patients who developed Cheyne-Stokes breathing as a result of high intracranial blood pressure.

Eyster[2] continued the work begun by Cushing and studied ten clinical cases of Cheyne-Stokes breathing. He demonstrated that there were two distinct groups of case in which this periodicity of breathing occurred—one associated with increased intracranial tension in which he found that the observations of Cushing were corroborated, namely, that in the period of breathing there is an increase of blood pressure and an acceleration of pulse rate. The other type occurred in association with cardio-vascular or renal disease, and in these exactly the opposite relation was found; that is to say, during the period of dyspnœa there was a fall of blood pressure and a slowing of the pulse, and during apnœa a rise of blood pressure and an increased pulse rate. The observations have further been corroborated by Pollock[3] in a study of a series of fifteen cases.

Pembrey, Beddard and French[6] reported a case of chronic Bright's disease in which the blood pressure was increased during the period of hyperpnœa, but the pulse rate was slowed ; during the period of apnœa the opposite was true. These findings do not accord with those of Cushing, Eyster and Pollock.

Little[3] refers to a case of chronic Bright's disease in which the pulse rate was slowed during dyspnœa and increased in rate during apnœa, the difference of rate being about twelve beats to the minute.

Pembrey and Allen[5] made careful observations on a case of chronic nephritis, both with reference to the pulse and respiration and to the composition of the alveolar air. In this case the pulse was considerably more rapid during the period of dyspnœa than during the period of apnœa.

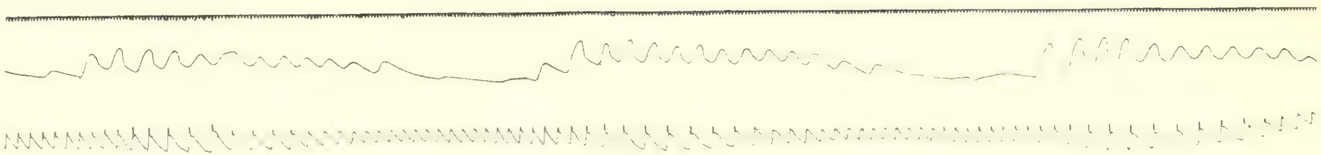
Mosso[4] mentions what he considers to be a third group of cases which occur in normal individuals in high altitudes. In these cases the phase of hyperpnœa is associated with a rise of blood pressure and a slowing of the pulse.

It would seem fair to conclude in so far as the observations thus far recorded are concerned that not all of the cases of Cheyne-Stokes breathing will fit readily into the two groups, but that these two groups as originally described by Eyster probably embrace most of the cases and that the exceptions are likely to be isolated instances.

The patient from whom the accompanying tracing was obtained was a man of forty-eight suffering from chronic Bright's disease. The first symptom of which he complained was shortness of breath on exertion about a year and a half previously. He had been in the Rhode Island Hospital under observation for about four months suffering a great deal from orthopnœa, general restlessness and sleepnessness. He had at the same time a very marked general anasarca. He had had some hypertension but his average blood pressure after admission was about 160. The urine showed a trace of albumen with a moderate number of hyaline casts. He had a functional phthalein test of 20 per cent. The quantity was rather scanty. His dyspnœa was more or less periodic, some days he was quite free from it. For about a month of his stay in the hospital his auricles were in a state of flutter. Subsequent to that the rhythm was normal. He was having occasionally periods of Cheyne-Stokes breathing and the tracing was taken at one time when the Cheyne-Stokes periodicity was well marked.

Explanation of tracing. The complete respiratory period lasts for about thirty seconds—approximately twenty seconds being occupied by the phase of dyspnœa and ten seconds by the phase of apnœa. In some instances there is not complete apnœa but the respirations are extremely shallow. It is noticeable that as a rule the first breath of the period of dyspnœa is usually the deepest and that the respirations fade out gradually.

The variation in the rate of pulse is extreme, a slow rate being found during the phase of dyspnœa and a rapid rate during apnœa. The slowest



Period about 30 seconds.

Phase of dyspnœa 20 seconds.

Phase of apnœa 10 seconds.

The "auricular flutter" persisted about five weeks, when the rhythm suddenly became normal except for the vagus irregularity which is shown in this tracing. In the middle line is a curve of respiration showing Cheyne-Stokes character.

Below is a tracing of the pulse showing how the amplitude and frequency alter. Time-marker, 1-5th sec..

beats would be approximately 45 to the minute and the rapid approximately 80. The slowest beats occur from about the third to the fifth respiration. There is a gradual increase and decrease in the rate, the most rapid rate being just about the beginning of apnœa. The tracing was taken with the Mackenzie polygraph. It is to be noticed that during apnœa a very distinct elevation of the base line of the pulse tracing accompanies the increased pulse rate, indicating an increased volume of blood in the arm and an increased blood pressure.

BIBLIOGRAPHY.

[1] Cushing. Johns Hopkins Hosp. Bull., 1901, xii, 290.
Amer. Journ. of med. Sci., 1902, cxxiv, 375.
Amer. Journ. of med. Sci., 1903, cxxv, 1017.

[2] Eyster. Journ. exper. Med., 1906, viii, 565.

[3] Little. Dublin Journ. of med. Sci., 1911, cxxxi, 321.

[4] Mosso. Archiv. ital. d. biol., 1905, xliii, 129, Fig. 21.

[5] Pembrey and Allen. Proc. of Physiol. Soc., 1905, p. xviii (Journ. Physiol., xxxii).

[6] Pembrey, Beddard and French. Pro. Physiol. Soc., 1906, p. vi (Journ. Physiol., xxxiv).

[7] Pollock. Archiv. intern. Med., 1912, ix, 406-408.

A CASE EXHIBITING A SLOW ATRIO-VENTRICULAR RHYTHM.

By E. E. LASLETT.

(*Hull.*)

It has been shown experimentally that an atrio-ventricular rhythm may appear in the mammalian heart when by various means the influence of the normal pacemaker is removed completely or its ryhthm is sufficiently retarded.

Clinical evidence of the existence of this rhythm is still scanty. Lewis[5] fully described a form of paroxysmal tachycardia due to impulses from a focus in the neighbourhood of the *A-V* node. In his paper he referred to a case published by Rihl. Cohn[1] has also published a similar case. Cowan and Ritchie,[3] and Cowan, Fleming and Kennedy,[2] have described cases with a short *a-c* interval in which they believe the rhythm had its origin in the *A-V* tissues. In three of the patients acute inflammation of the *A-V* node was found post-mortem. Recently Hume[4] has published a paper on the types of cardiac irregularity met with in diphtheria. In three of the patients at some period of the illness the venous pulse was found to be of the ventricular form, in association with a regular pulse which was rapid in two of the cases, slow in the third. In the first case transitions were observed from the ventricular to auricular venous pulse. Hume concluded that the auricles and ventricles contracted together in response to a stimulus from a common focus in the *A-V* tissues. In the second and third cases acute inflammation was found in the *S-A* node while the *A-V* node was unaffected.

In the case here described there is evidence that the normal pacemaker was in abeyance for periods of varying duration during which the heart responded to stimuli of slow rhythm emanating from a focus in the junctional tissues.

History. The patient is a rather frail overgrown boy who was first seen on June the 16th, 1914, suffering from slight pain in one hip and general malaise. The illness was slight and in a few days, under salicylate of soda, he was up and in his usual state of health. Examination of the circulatory system revealed nothing abnormal except the presence of a slow and somewhat irregular pulse. This irregularity would have been ascribed without further examination to an unimportant sinus arythmia had it not been noticed that some of the pulse beats after the shorter pauses were accompanied by an extra large pulsation in the veins of the neck. Polygraph curves were therefore taken which showed the irregularities to be presently described.

Polygraph curves. All the figures are taken from one long curve and it will be convenient briefly to describe the irregularities and the form of the associated venous pulse as they appear in sequence in the curve. The first portion showed for a long period the normal *S-A* sequence (Fig. 1). It will be noticed that the rate is slow with some degree of arythmia. The auricular wave is large and the *a-c* interval normal. There now appeared occasional large waves in the jugular pulse which coincided with the calculated position of the carotid wave. Such a wave is shown in the second cycle of Fig. 3 (reading left to right). This wave is not preceded by an auricular

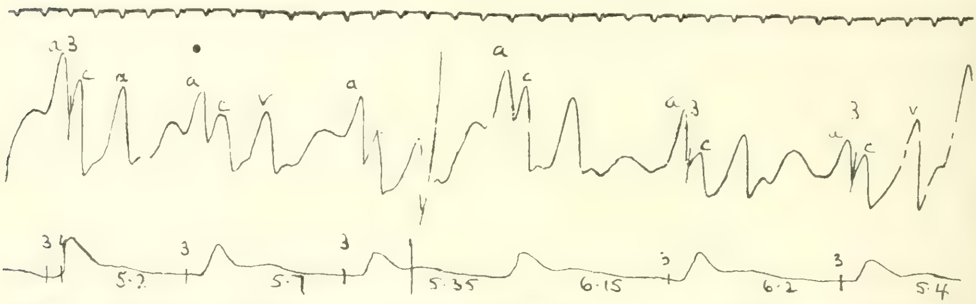


Fig. 1. Jugular and radial curves to show the normal sinus sequence. Time marker in this and the remaining figures indicates one-fifth of a second. Pulse rate 53 per minute.

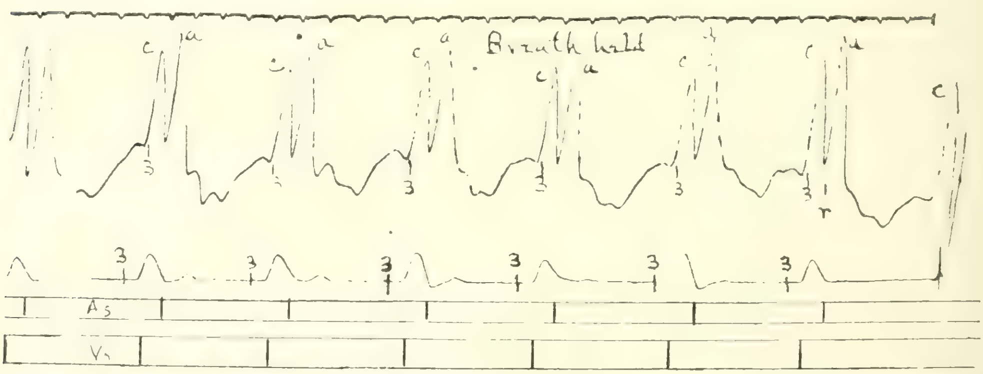


Fig. 2. Jugular and radial curves. To show the ventricular form of venous pulse. It is thought that the second wave of each cycle represents the auricular systole which follows the ventricular at a constant interval. The diagram and that in Fig. 3 were kindly drawn for me in Dr. Mackenzie's laboratory. The pulse rate is 59.

wave and judging from its increased height it may be assumed that it is due to the coincidence of *a* and *c* waves; that is to say, the auricles and ventricles contract simultaneously. Further on in the curve the large waves appeared in groups of three to five. An example of these groups is illustrated in Fig. 3. In the fifth and sixth cycles of this figure (left to right) the upstroke of the venous wave commences slightly before the calculated position of the carotid pulse, which is indicated by a slight angle in the curve. At the seventh cycle the single wave exactly coincides with the position of the

carotid pulse. At the ninth cycle the *S-A* sequence is resumed. The tenth shows only a single tall wave, and in the immediately following portion of the curve (not illustrated) there were only single waves with no indication of a separate auricular contraction.

In later portions of the curve there were long stretches in which there was no indication of the auricular contraction in its normal position. The tall wave, which commenced at the same time as the ventricular systole, was either single or showed usually two peaks separated by a nearly constant interval except where there were transitions from one form to the other. These transitions were in either direction and occurred in several places. This form of the venous curve is illustrated in Fig. 2, 4 and 5.

The onset of the new rhythm is shown six times in the curve taken. In five of these the venous pulse showed a single wave which persisted for several cycles. On the sixth occasion the form of the wave which accompanies the first beat of the new rhythm could not be completely determined, but at the second beat a well marked double-peak appeared, and this was maintained as the rhythm proceeded (Fig. 4). The double peak appeared to be the more characteristic and it tended to persist with little change for comparatively long periods. On occasion there was a gradual transition to a single wave for a few cycles and back again. The single wave thus observed was usually broader than the single wave observed at the beginning of the new rhythm. Occasionally the broad single wave was replaced by a narrow one which was immediately followed by a second of much diminished amplitude.

Wherever the second peak of the venous wave was distinct it maintained its position relative to the first with remarkable constancy, and the most probable interpretation seems to be that it represents the auricular contraction which follows the ventricular at a short constant interval. The diagram which accompanies Fig. 2 illustrates this relationship.

Discussion. The ventricular form of venous pulse in association with a regular rhythm may be present in several forms of abnormal cardiac activity, which Hume discussed in his paper. Bearing in mind the slow rate of the new rhythm, his arguments may be applied with even greater cogency to the present case and it is necessary to consider only the possibility of the presence of auricular fibrillation with complete heart-block. Two facts make this interpretation improbable. (1) When the *S-A* sequence prevailed there was no evidence of impairment of conductivity. (2) The occurrence of isolated waves of the ventricular form could not be explained in this way.

The only possible interpretation would seem to be that the auricles and ventricles were contracting simultaneously in response to a stimulus arising from a focus between them, *i.e.*, probably in the junctional tissues.

The variations in the form of the ventricular venous pulse bear on the possible localisation of the new pacemaker and the constancy of its position. The transition from a single to a double wave would suggest that there was a

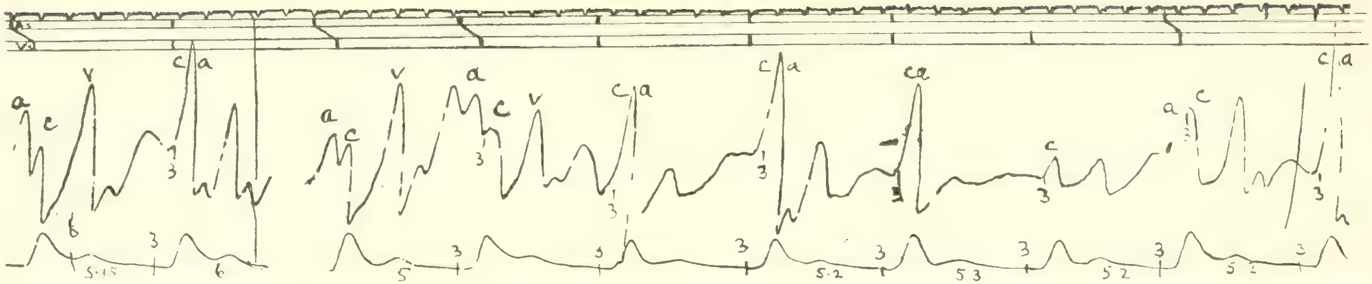


Fig. 3. Jugular and radial curves. To show alternation of normal and new rhythms. At the 5th and 6th cycles (left to right) the upstroke of the *c-a* wave commences slightly before the calculated position of the carotid wave. This is referred to in the text. The curve to the right of this figure showed a continuous ventricular venous pulse with a single wave.

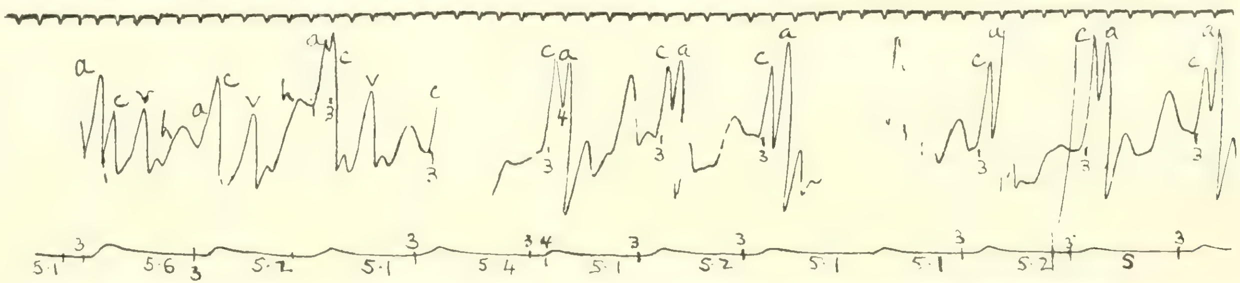


Fig. 4. Jugular and radial curves. To show the early appearance of the double wave in the venous pulse after the onset of the new rhythm. The rate slightly increases as the rhythm proceeds.

Fig. 5. Jugular and radial curves. To show the transition from a double to a single wave in the ventricular venous pulse. At the last two cycles there is apparently an emergence of *a* before *c*. Beyond the ordinate the normal sinus sequence is resumed. Pulse rate, 60.

gradual shifting downwards of the focus of stimulus formation. There is some experimental evidence for this (Eyster and Meek). But there is another possible explanation of the transitions. At the onset of a new rhythm such as is here described it is not improbable that the normal pacemaker might continue to influence the auricles for a short period, if its rate were nearly equal to that of the new pacemaker. Thus the occurrence of single waves at the onset would be due to coincidence of an auricular contraction of sinus origin with the ventricular wave of the new rhythm. Similarly escape of the sinus would account for the form of the waves at the end of Fig. 5. With regard to the transition forms observed in the midst of a series of double peaked waves, it is possible that these might be due to mechanical defect. The evidence available is not, however, sufficient to permit a definite conclusion as to which is the correct interpretation.

The pulse rate when the normal rhythm prevailed was slightly but distinctly less than the rate of the atrio-ventricular rhythm, 53 as compared with 59 per minute. There was, further, a greater degree of arythmia, the maximum variation in the length of cycle being ·2 sec. in the former and ·08 sec. in the latter. This relation is noteworthy and perhaps would not have been expected. Williams and James[8] in their case of reversed cardiac mechanism found that the frequency of the *S-A* rhythm was slightly greater than when the ventricle was dominant. Lewis[6] has shown that when an *A-V* rhythm has been established by cooling the sinus region vagal stimulation brings about slowing and escape of the *S-A* rhythm, which is maintained as long as the stimulation continues. Eventually the *A-V* rhythm is re-established. It is possible that in the present case during the dominance of the normal pacemaker there was continued increase of the vagus tone which retarded the *A-V* rhythm to a rate below that of the sinus. When, on the other hand, the vagus tone diminished the *A-V* rhythm became established. Unfortunately the effect of vagus pressure was not tried at this time.

As bearing on this suggestion it should be mentioned that on June the 20th a long polygraph curve was taken. The normal rhythm was maintained throughout and the pulse rate (54) and degree of arythmia were about the same as when the *S-A* rhythm was present on June the 16th. Again on July the 12th a curve was taken. The pulse rate was now 66 per minute. Vagus pressure and also pressure on the eyeball were found to cause slight slowing, the longest interval observed being six-fifths of a second, but there was no dislocation of the pacemaker.

Summary.

(1.) A case is described in which at times the auricular form of venous pulse was replaced by the ventricular. The pulse was slow throughout. It is believed that the new rhythm had its origin somewhere in the *A-V* tissues.

(2.) The rate of the *S-A* rhythm was slightly slower with a higher degree of arythmia than that of the new pacemaker. It is suggested that this may have been due to increased vagal tone which depressed the rate of the new rhythm below that of the normal pacemaker and allowed escape of the latter.

BIBLIOGRAPHY.

[1] Cohn. Heart, 1910-11, 2, 170.

[2] Cowan, Fleming and Kennedy. Lancet, 1912, 1, 277.

[3] Cowan and Ritchie. Quart. Journ. of Med., 1910-11, iv, 55

[4] Hume. Heart, 1913-14, v, 25.

[5] Lewis. Heart, 1909-10, i, 306.

[6] Lewis. Heart, 1913-14, v, 247.

[7] Meek and Eyster. Heart, 1913-14, v, 227.

[8] Williams and James. Heart, 1913-14, v, 109.

THE PHYLOGENETIC DEVELOPMENT OF THE BULBAR AND VENTRICULAR SEPTA OF THE HEART.*

By JANE I. ROBERTSON.

(*From the Victoria Infirmary, Glasgow.*)

The bulbar and ventricular septa appear in association with the development of a pulmonary system of respiration and circulation, and the consequent need for the separation of the oxygenated and non-oxygenated blood streams. The complete subdivision of the ventricle and bulbus into arterial and venous channels is correlated with the degree of development of the lungs; when the latter are sufficiently voluminous to deal with the whole of the venous content of the heart at once, the longitudinal bilateral division of that organ is complete.

The progressive development and association of the bulbar and interventricular septa is well seen in a comparative study of elasmobranch, dipnoan, reptilian and mammalian hearts.

Bulbus cordis.

Early in development the bulbus cordis of each of the series presents practically the same features. At first all are comparatively straight tubular structures and all are provided internally with a number of endothelial ridges or cushions.

The developing elasmobranch[3] bulbus is provided with four longitudinal endothelial ridges (Fig. 1, *I*, *d*1, &c.), one dorsal, one ventral and two lateral. Of these the ventral ridge frequently disappears, and, in the adult, the remaining ridges are broken up into rows of more or less functional pocket valves. The adult bulbus is a straight tube with a well developed compact muscular coat and the venous blood passes along it from the simple undivided auricle and ventricle to the branchial vessels. Regurgitation is prevented by the peristaltic contraction of the bulbar walls and the action of such of the pocket valves as are functional.

The developing dipnoan[6] bulbus is also straight at first, and four endothelial ridges appear distally and proximally, though there are none for a time in the middle region. Distal ridges 2 and 4 (Fig. 1, *II*, (*a*) *d*2, *d*4) disappear again, and of the proximal ridges the dorsal and two lateral ones (Fig. 1, *II*, (*e*) *p.* 2 *B*, *p.* 1 *C*, *p.* 3 *D*) persist in the adult merely as vestigial pocket valves. The straight bulbus now kinks on itself bayonet-wise in its middle part, forming the transverse or middle segment which expands ventrally and forwards round its rigid right wall, while it is separated from

* Published under the tenure of a Beit Memorial Fellowship.

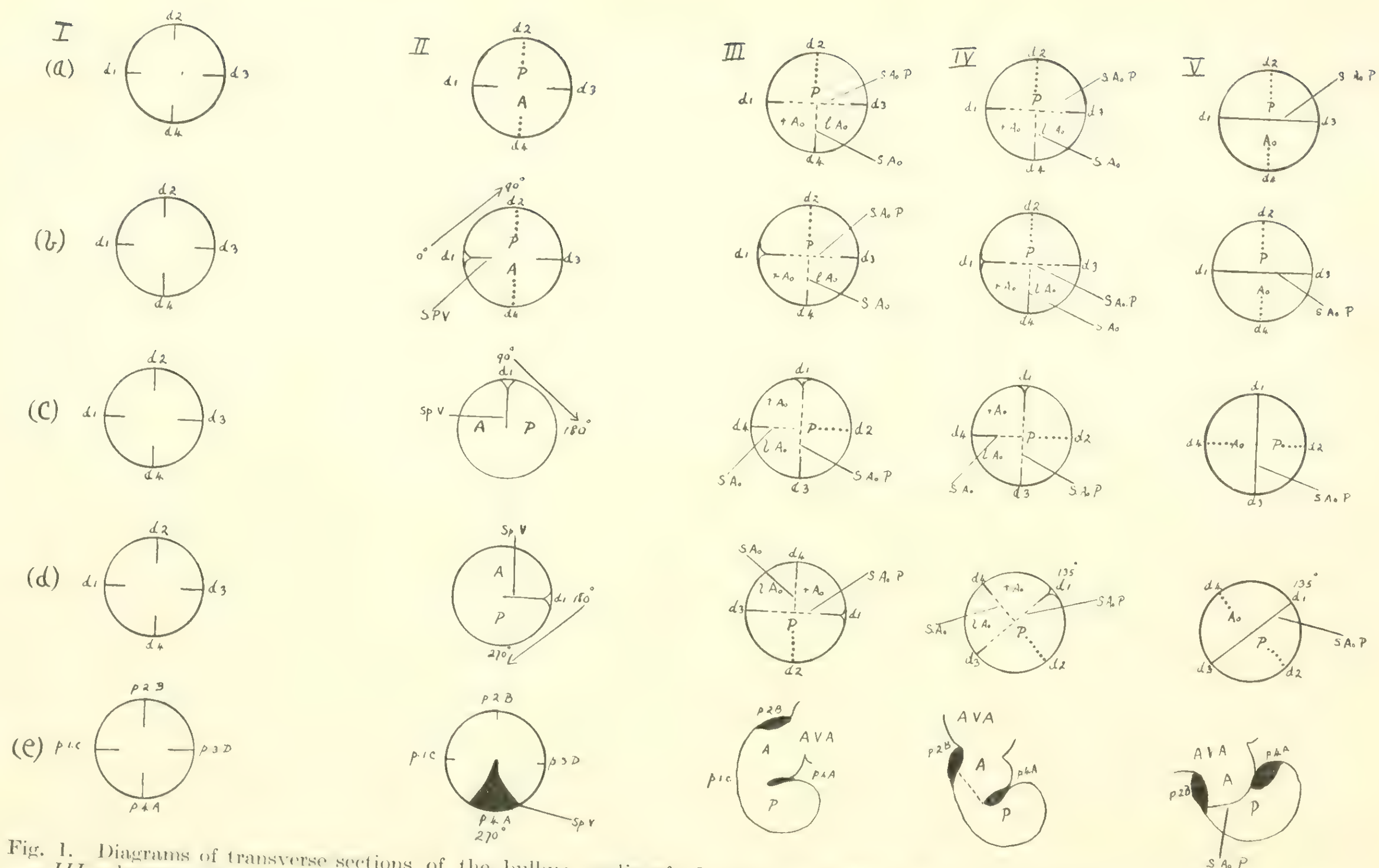


Fig. 1. Diagrams of transverse sections of the bulbus cordis of *I*, an elasmobranch fish; *II*, a dipnoan (*Lepidosiren paradoxa*); *III*, a lower reptile (*Lacerta agilis*); *IV*, a higher reptile (*Crocodilus niloticus*); *V*, a mammal. Row (*a*) is at the level of the distal bulbar extremity, row (*b*) at the distal bulbar constriction, row (*c*) between the distal and proximal bulbar constrictions, row (*d*) at the proximal constrictions, and row (*e*) at the distal extremity of the proximal bulbar segment. The short dotted lines in the four upper rows of diagrams indicate those endothelial ridges that appear only temporarily; the dashed lines indicate the septa that develop secondarily between the primary endothelial ridges. The ventral surface of the diagrams is towards the reader.

A, arterial channel; *Ao*, aorta; *A.V.A*, auriculo-ventricular aperture; *d*1, *d*2, *d*3, *d*4, distal endothelial ridges 1, &c.; *l.Ao*, left aorta; *P*, pulmonary channel or vessel; *p*. 4 *A*, *p*. 1 *C*, *p*. 2 *B*, *p*. 3 *D*, proximal endothelial ridges, 4 *A*, &c.; *r.Ao*, right aorta; *S.Ao*, aortic-septum; *S.Ao.P*, aortico-pulmonary septum; *Sp.V*, Spiral valve.

the proximal segment by the proximal, and from the distal by the distal bulbar constriction. The rigid wall between the two constrictions is very short, and as the middle part of the bulbus expands round it, it gives rise in the interior to a fold, the bulbar ledge, extending from the right side of the distal to the left side of the proximal constriction. At the same time the right distal ridge 1 extends proximally along the bulbar fold as far as the proximal constriction and here it is brought into contact round the left rim of that constriction with the left distal end of the now very prominent proximal bulbar ridge 4 *A* (Fig. 1, *II*, (*b*), (*c*), (*d*), *d*1, and (*e*), *p*. 4 *A*). The two ridges fuse and form a spiral valve that describes an angle of 270° in its course from the right distal to the ventral proximal bulbar walls (Fig. 1, *II*, *Sp.V.*). Distal ridge 3 extends as far as the distal bulbar constriction (Fig. 1, *II*, (*a*), (*b*), *d*3), and with ridge 1 incompletely divides this segment of the bulbus into ventral or arterial and dorsal or venous channels (Fig. 1, *II*, *P.A.*). Just at their distal extremities the two ridges join to form a very short complete aortico-pulmonary septum in the short ventral aorta (truncus arteriosus) and fuse with the dorsal wall immediately in front of the dorsal, posterior or pulmonary pairs of aortic arches. The proximal segment of the bulbus has a compact muscular coat, while that of the middle and distal segments is comparatively poorly developed. The spiral valve guides the venous and arterial blood streams—the dipnoans have a pulmonary respiration and circulation—from the proximal end of the bulbus, where they are placed right and left, to the distal end, where they are situated dorsally and ventrally respectively. Thus the venous blood reaches the dorsal or pulmonary arches and the arterial blood the ventral or aortic arches (Fig. 1, *II*, *P.A.*). It is of interest to note that the bulbus cordis of *Ceratodus*,[5] the most fish-like of the dipnoans, is furnished with longitudinal rows of pocket valves as well as with a rudimentary spiral valve. From certain markings on the spiral valve of *Ceratodus* and *Lepidosiren paradoxa*, and also from the presence in the latter of the proximal vestigial pocket valves, it is probable that the longitudinal valvular structures in the dipnoan bulbus are derived from the fusion of rows of valves similar to those in the elasmobranch.

The bulbus cordis of the lower reptiles as exemplified by *Lacerta agilis*[2] is also straight at first and provided with four distal endothelial ridges (Fig. 1, *III*, (*a*)) : proximally, however, only three ridges appear, while the left lateral ridge, 3 *D*, does not develop at all, and right lateral ridge 1 *C* disappears again later. The absence of any endothelial structure on the left proximal bulbar wall, between the auriculo-ventricular and bulbo-ventricular apertures, is probably associated with the expansion of the ventricle up round the base of the heart and the progressive shortening of the wall till, finally, the apertures on either side of it are in free communication below its greatly heightened proximal border (Fig. 1 *III*, (*e*)). Very soon the bulbus becomes bayonet-shaped, distal ridge 1 extends proximally along the bulbar fold, and, with the proximal ventral

ridge 4 *A*, forms temporarily a spiral ridge similar to the dipnoan valve. The bulbus, however, straightens again and the spiral twisting is distributed over a longer area, affecting all the four distal ridges equally, so that they describe a clockwise angle of about 180° from their distal to their proximal extremities at the distal and middle bulbar junction (Fig. 1, *III*, (*a*) to (*d*)). Distal ridge 2 disappears finally except just at its proximal extremity where it helps later to form the semilunar valves. At the same time the aortico-pulmonary septum grows down from the anterior margins of the pulmonary arches, and as it does so the tissues of the developing truncus arteriosus replace those of the distal part of the bulbus. Ridges 1 and 3 are joined by the aortico-pulmonary septum which follows the curve that they describe, so that finally the truncus is completely divided into pulmonary and aortic channels that twist round one another 180°. The aortic channel is subdivided into right and left vessels by the junction of distal ridge 4 across its lumen with the aortico-pulmonary septum, forming the aortic septum (Fig. 1, *III*, *S.Ao.P.*, *S.Ao.*). Meanwhile the proximal segment of the bulbus has been taken up into the ventricle and the proximal constriction straightened out and, owing to the expansion of the new distal part of the ventricle ventrally and to the left (Fig. 1, *III*, (*e*)), and also partly to the development of the ventral interventricular septum, proximal ridge 4 *A* comes to lie on the left and to project into the lumen of the ventricle (Fig. 1, *III*, (*e*), *p.* 4 *A*). The left pillar of the proximal border of the aortico-pulmonary septum—that is, distal ridge 1—passes directly into proximal ridge 4 *A*, and ultimately, too, the proximal extremity of distal ridge 4—the dorsal pillar of the aortic septum—merges with the large endothelial cushion formed by proximal ridge 2 *B* (*cf.* Fig. 1, *III*, (*d*) and (*e*)). It will be noticed that the expansion of the new distal part of the ventricle occurs ventral to the situation of the bulbar ledge on the left wall of the bulbus ; the unyielding nature of the ledge has already been referred to. The proximal bulbar segment is thus engulfed by the expanding ventricle, while the distal part is replaced by the truncus arteriosus ; between the two there is left a vestigial band of compact bulbar musculature that supports the semilunar valves guarding the bases of the great vessels. The proximal extremities of the fused distal ridges 1 and 3 afford the three septal valves, while the marginal ones are derived from distal ridge 2, part of 3 and 4 respectively. In the adult the truncus arteriosus sweeps in a gentle curve from right to left and consists of the pulmonary and two aortic vessels firmly bound together in a common connective tissue sheath ; the spiral disposition of the vessels is indicated by shallow external grooves. As will be pointed out later, the pulmonary vessel receives unmixed venous blood, the left aorta mingled venous and arterial, while the right aorta receives predominently arterial blood. Once the blood has reached the great vessels it is kept completely separate as far as the truncus arteriosus is concerned.

The development of the bulbus cordis of the higher reptiles, such as the crocodile,[4] is exactly similar, only as the right to left expansion of the new

distal part of the ventricle is more marked than in the lizard, and is also accompanied by a certain amount of rotation of the ventral and dorsal ventricular limbs counter-clockwise round one another, proximal endothelial cushion 4 *A* is placed more to the left, and proximal cushion 2*B* to the right (Fig. 1, *IV*, (*d*)). Ultimately, therefore, at the junction of the distal and proximal ridges, the aortico-pulmonary septum has only described an angle of about 135° from its distal to its proximal extremity (Fig. 1, *IV*, (*d*), *S.Ao.P.*). Further, in the crocodile the two proximal, dorsal and ventral, endothelial cushions unite across what is now the distal part of the right ventricle along the free border of the aortic septum, and so separate the orifices of the pulmonary artery and left aorta on the right from the orifice of the right aorta on the left (Fig. 1, *IV*, (*d*) and (*e*)). As the interventricular septum is complete in the crocodile, the two former vessels in the adult receive venous and the latter arterial blood, the two aortæ, however, communicate with one another near their bases by means of the secondarily developed foramen Panizzæ,[2] so that even in the higher reptiles the systemic circulation is not yet wholly arterial. The orifices of the great vessels are guarded by semilunar valves and a vestige of compact bulbar musculature affords them support. In the crocodile a slip of this musculature extends across the bulbus in the free proximal border of the aortico-pulmonary septum so that there is a double muscular ring encircling the valves.

The development of the mammalian bulbus[1] is very similar to that of the crocodile. Of the four distal endothelial ridges, ridges 2 and 4 persist only at their proximal ends to assist in forming the semilunar valves; proximally only two endothelial cushions, one ventral and one dorsal, appear at all (Fig. 1, *V*, (*a*) and (*c*)). At first the bulbus is short and straight, it lengthens and becomes bayonet-shaped for a time, the double curve then straightens out again and the proximal bulbar segment is taken up into the right ventricle, while its distal segment becomes the truncus arteriosus. The aortico-pulmonary septum is formed as in the reptile, but the early stage of a separate spiral ridge does not occur, the septum is continued into the distal part of the right ventricle by the union of the proximal ridges 4 *A* and 2 *B* (Fig. 1, *V*, (*e*), *S.Ao.P.*). In the mammal the left aorta disappears and the truncus arteriosus is divided into single pulmonary and aortic stems that twist round one another about 135° counterclockwise from their proximal to their distal extremities. Connective tissue folds grow in from either side along the aortico-pulmonary septum and finally the two vessels form separate trunks at the base of the heart. The semilunar valves are formed by the extremely shortened distal bulbar ridges. Ridges 1 and 3 afford the lateral, and ridges 2 and 4 the ventral and dorsal valves for the pulmonary artery and aorta respectively. In the adult, subsequent upon the encroachment of the truncus arteriosus and of the ventricle, only traces of any compact bulbar musculature are present at the proximal extremities of the great valves.

Interventricular septum.

In the elasmobranch the ascending limb of the heart is placed close against the right side of the descending limb, and between them is the extremely short cranial ventricular curvature forming the floor of the left segment of the circular bulbo-ventricular groove (Fig. 2, *I*, *B.V.gr.*). The proximal and distal ventricular apertures are placed side by side (Fig. 2, *I*, *A.V.A.*, *B.V.A.*), the former on the left, the latter on the right, and the bulbo-ventricular groove passes sagittally between them. The ventricular walls are composed of a thick spongy musculature whose main trabeculæ pass circularly round the ventricle at right angles to its long axis and diverge from the cranial curvature towards the proximal and distal aperture. In such a ventricle the venous blood from the undivided auricle is discharged into the bulbus cordis, while regurgitation is prevented by the auriculo-ventricular valves. The course of the blood in the bulbus has already been referred to.

In the dipnoans the heart loop as a whole is at first deviated to the right; presently, however, it rotates counterclockwise from right to left and the long axis of the ventricle becomes parallel to that of the body, the auriculo-ventricular aperture being placed directly dorsal to the bulbo-ventricular aperture (Fig. 2, *II*, *A.V.A.*, *B.V.A.*). The dorsal strip of ventricle, intervening between the bulbus and the auricle, is reduced to a mere vestige, and this segment of the bulbo-ventricular groove now forms the bulbo-auricular groove (Fig. 2, *II*, *B.A.gr.*). The ventricular musculature develops as little subendothelial buds whose clubbed tips join to form arches converging from the walls and floor of the ventricle on to the ventral surface of the developing auriculo-ventricular plug situated on the posterior rim of the auriculo-ventricular opening (Fig. 2, *II*, *A.V.P.*, *I.V.S.*). The dipnoans have no auriculo-ventricular valves of the usual type and this button-like cartilaginous plug performs their functions, lying in the auriculo-ventricular aperture and when approximated against it closing it accurately. The muscular fibres attached to the plug form in the adult a solid keel of muscle whose fibres radiate from the plug to the ventral and lateral walls of the ventricle. The free border of this keel or septum passes immediately proximal to the bulbar opening to be inserted into the ventral wall of the ventricle, that is, directly in line with the proximal part of the spiral valve (Fig. 2, *II*, *Sp.V.*). The general arrangement of this ventricular musculature is comparable with that of the elasmobranch with the difference, firstly, that in the dipnoan the circular fibres diverging along the sides of the heart are caught up dorsally and proximally onto the auriculo-ventricular plug to form the incomplete interventricular septum, and, secondly, owing to the extreme narrowness of the bulbo-auricular groove, they tend to be inserted more directly into the rims of the two ventricular apertures and so to become less oblique. In this heart venous blood from the right, and arterial blood from the left, auricle, pass along the right and left sides of the interventricular septum respectively, and each is guided into the proximal part of the bulbus

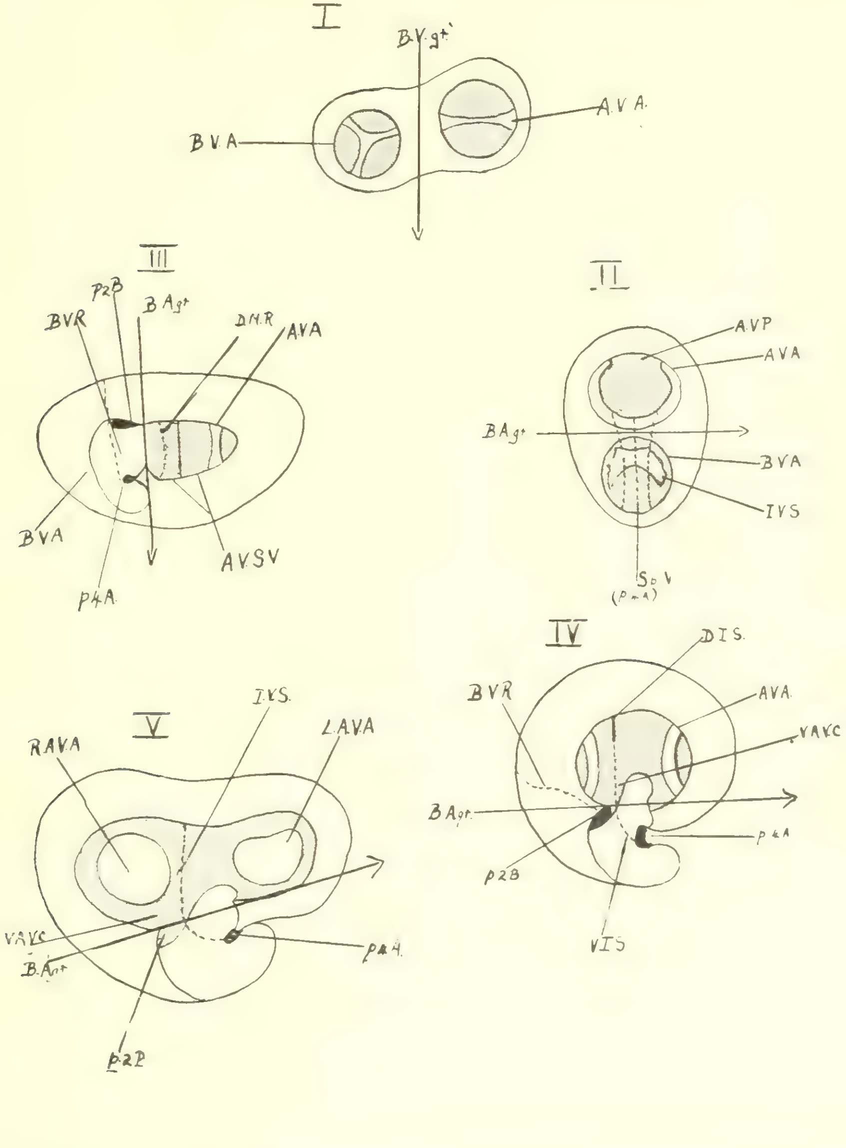


Fig. 2.—Diagrams of transverse sections at the ventricular bases of I, an elasmobranch fish; II, a dipnoan (*Lepidosiren paradoxa*); III, a lower reptile (*Lacerta agilis*); IV, a higher reptile (*Crocodilus niloticus*); V, a mammal.

A.V.A., auriculo-ventricular aperture; *A.V.P.*, auriculo-ventricular plug; *B.A.gr.*, bulbo-auricular groove; *B.V.A.*, bulbo-ventricular aperture; *B.V.gr.*, bulbo-ventricular groove; *B.V.R.*, bulbo-ventricular ridge; *D.I.S.*, dorsal interventricular septum; *D.M.R.*, dorsal muscular ridge; *I.A.S.*, interventricular septum; *L.A.V.A.*, left auriculo-ventricular aperture; *p. 4 A*, proximal ventral bulbar endothelial ridge; *p. 2 B*, proximal dorsal bulbar endothelial ridge; *R.A.V.A.*, right auriculo-ventricular aperture; *Sp.V.* (*p. 4 A*), spiral valve (proximal endothelial ridge 4 *A*); *V.A.V.C.*, ventral auriculo-ventricular endothelial cushion; *V.I.S.*, ventral interventricular septum.

on the corresponding side of the spiral valve. The course of the circulation in the bulbus has already been considered. As the auricular, ventricular and bulbar septa are all incomplete, the perfect separation of the two blood streams is probably not accomplished, but the right and left sides of the heart deal with mainly venous and arterial contents respectively.

The reptilian ventricle is early deviated to the right, similarly as in the elasmobranch. The proximal and distal ventricular orifices are placed left and right respectively, and the bulbo-auricular groove is directed sagittally between them (Fig. 2, *III*, *A.V.A.*, *B.V.A.*, and *B.A.gr.*). The ventricular musculature develops as little arches forming a series of ridges approximately at right angles to the long axis of the ventricle, diverging towards the fundus and converging towards the base. These muscular ridges become more and more prominent with the general peripheral expansion of the ventricle, but particular ones tend to outstrip the rest. At the left end of the ventricle the most prominent muscular ridges are situated to the right below the right septal auriculo-ventricular valve (Fig. 2, *III*, *D.M.R.*) and pass from the dorsal to the ventral rims of that aperture. At the right end of the ventricle the ridges on the right wall below the bulbar aperture become massed together, they are attached distally to the proximal bulbar endothelial cushion 4 *A* (Fig. 2, *III*, *p.* 4 *A*, *B.V.R.*) and extend dorsally and slightly to the right to sink into the dorsal ventricular wall below dorsal endothelial cushion 2 *B*. From its relations this right muscular ridge may be called the bulbo-ventricular ridge. The ventricular musculature encroaches on the right and ventral proximal bulbar walls, effacing the proximal constriction, and presently rifts appear, ventrally and on the right, between the bulbo-ventricular ridge and the outer wall of the heart, giving rise to a new right ventral ventricular cavity developed in the thickness of the new right ventral ventricular wall that has replaced the proximal bulbar wall in this region. The new distal ventricular wall expands ventrally and to the left, and the bulbo-ventricular ridge now projects from the left at the bulbo-ventricular junction into the cavity of the ventricle, with proximal endothelial ridge 4 *A* situated on its left distal crest (Fig. 2, *III*, *B.V.R.*, *p.* 4 *A*). The prominent left muscular ridge (Fig. 2, *III*, *D.M.R.*) divides the primitive common ventricle into a larger left and a smaller right compartment, while the bulbo-ventricular ridge (Fig. 2, *III*, *B.V.R.*) divides the whole of the primitive ventricle from the newly developed right ventral ventricular cavity. The two muscular ridges are nearly parallel, while intervening between them dorsally is a powerful muscular band arching up into the ventricular roof in the region of the bulbo-auricular groove (Fig. 2, *III*, *B.A.gr.*). Such a heart presumably acts as follows. Venous blood from the right auricle passes down the right auriculo-ventricular septal valve and is guided over the upper free border of the bulbo-ventricular ridge into the right ventral ventricular compartments; when that compartment is filled the rest of the venous blood will be accommodated in the right part of the left dorsal ventricle. The left auricle meanwhile discharges the whole of its contents

into the left side of the dorsal ventricle. On contraction of the ventricle the bulbo-ventricular ridge and the powerful dorsal column just referred to are approximated and together shut off the right ventral cavity from the left dorsal compartment, while the venous blood contained in the former is guided along the right side of the bulbo-ventricular ridge ventrally and to the left into the pulmonary artery. Simultaneously the mixed arterial and venous blood from the dorsal cavity passes ventrally and along the left dorsal side of the bulbo-ventricular ridge and so into the two aortic openings. The left aorta probably receives mainly venous and the right predominantly, if not wholly, arterial blood.

The development of the ventricle in the crocodile corresponds closely with that of the lizard, but in the former the left and right positions of the auriculo-ventricular and bulbo-ventricular apertures is altered during development, the former extending to the right and the latter more to the left than in the lizard. The result is that the distal comes to lie ventral to the proximal opening, and the left ventral part of the bulbo-ventricular ridge is carried across the main dorsal ventricular ridge at a marked angle (Fig. 2, *IV*, *D.M.R.*, *B.V.R.*). The dorsal ridge and the left ventral segment of the bulbo-ventricular ridge, distal to its intersection with the former, may now be called the dorsal and ventral interventricular septa respectively; at their point of junction below the adjacent segments of the distal and proximal ventricular apertures, they form a V shaped notch surrounded by endothelial structures—the interventricular foramen. In the crocodile (as in the lizard) the ventral interventricular septum (bulbo-ventricular ridge) is continuous with the left pillar of the aortico-pulmonary septum and extends to the right along its ventral border as far as the insertion of the aortic septum. In the lizard, the free border of the aortico-pulmonary septum, on the right of the aortic septum, consists wholly of tissue derived from the right and left distal bulbar cushions; in the crocodile, however, a strip of muscle appears in this border extending from the ventral interventricular septum to the right wall of the bulbus and continuous there with the musculature of the heart wall. The proximal termination of the aortico-pulmonary septum in the crocodile, therefore, is muscular in character. The dorsal septum grows ventrally a varying distance along the under surface of the fused auriculo-ventricular endothelial cushions, receiving from them an endothelial extension along its free border. Similarly proximal bulbar endothelial cushion 4 *A* extends along the free border of the ventral septum, while distally it fuses along the free border of the aortic septum across the bulbar aperture with cushion 4 *B* (Fig. 1, *IV*, (*d*) and (*e*)) which in turn, owing to the abolition of the mesial bulbar wall, fuses with the ventral auriculo-ventricular cushion (Fig. 2, *IV*, *V.A.V.C.*, *p.* 2 *B.*). This endothelial ring closes across the interventricular foramen, forming the pars membranacea septi, completing the interventricular septum. The ventricle is now divided into right and left compartments, while the left aorta and pulmonary artery on the right and ventrally are separated from the right

aorta on the left and dorsally. In different species of crocodile the pars is of very varying extent. In the crocodile, therefore, the right ventricle is derived from the right division of the primitive common ventricle and the new right ventral cavity developed in the right ventral wall of the proximal part of the bulbus cordis, while the left ventricle is formed by the left division of the primitive common ventricle. In this heart the venous blood from the right auricle passes ventrally and to the left to enter the pulmonary artery and left aorta, while arterial blood from the left auricle passes ventrally and a little to the right to enter the right aorta. The further course of the blood in the truncus arteriosus has already been noted.

The separation of the mammalian ventricle into right and left compartments is achieved very much as in the crocodile. The proximal and distal ventricular apertures are at first situated side by side and the bulbo-auricular groove is placed sagittally between them. The proximal aperture presently extends to the right, and the distal to the left, and a certain degree of rotation of the heart as a whole occurs, so that finally the former opening lies directly dorsal to the latter and the bulbo-auricular groove is carried a little to the left of the frontal plane (Fig. 2, *V.*, *B.A.gr.*). The ventral and right to left expansion of the bulbus is more marked even than in the crocodile, and the proximal bulbar cushion 2 *B* extends further to the right (Fig. 2, *V*, *p.* 2 *B.*). The interventricular septum develops as a powerful semilunar muscular ridge extending across the fundus of the ventricle, its dorsal horn passing into the dorsal wall nearer the right than the left edge of the fused auriculo-ventricular cushions, while its ventral horn is deflected to the left and terminates in proximal bulbar cushion 4 *A* (Fig. 2, *V*, *I.V.S.*, *p.* 2 *B.*). The dorsal horn extends ventrally along the fused auriculo-ventricular cushions to the dorsal rim of the bulbar aperture, while the ventral horn extends to the right, along the whole length of the border of the aortico-pulmonary septum, so that the separation of the aortic and pulmonary channels is complete. At first the common bulbar orifice is on the right of the septum and the blood from the left side of the heart reaches it through the notch between the two ventricular horns, that is through the interventricular foramen ; later, however, the ventral expansion of the ventricle and the development of the interventricular septum, &c., displace the aortic channel till it is situated over the septum and then the endothelial rims of the foramen, derived similarly as in the crocodile, fuse round the right side of the aorta and the interventricular septum is complete. The fusion of the septum round the right side of the aorta seems to be largely determined by the shorter distance between its dorsal and ventral horns, and by the completion of the endothelial ring on that side, and also, perhaps, by the action of the arterial blood stream moulding a path to the aorta across its left margin.

Summary.

As the preceding notes clearly indicate, the development of the ventricular and bulbar septa is largely determined by two factors, the need for the separation of the arterial and venous blood streams and the posterior position of the sixth or pulmonary aortic arches. The elasmobranch heart, with its undivided ventricle and straight muscular bulbus provided with longitudinal rows of valves, is well adapted for the propulsion of a homogeneous blood stream forwards to the branchial arteries. In the dipnoan, however, where there are two differentiated streams to be dealt with, several modifications occur. The ventricle, homologous with that of the elasmobranch, is incompletely but symmetrically divided into right and left compartments by the interventricular septum derived from the circular musculature; the long bulbus is kinked on itself and the spiral valve (probably homologous with the elasmobranch pocket valves) appears, guiding the venous blood from the right side of the heart through an angle of 270° to the posterior pulmonary arches. The development of the spiral and the left distal bulbar valves is correlated with a diminution in the muscularity of the distal and middle bulbar segments.

In the lizard a similar result is achieved in the ventricle by somewhat different means. The primitive common ventricle, homologous with that of elasmobranch and dipnoan, is incompletely and symmetrically divided into right and left compartments by the dorsal muscular ridge derived from the circular ventricular musculature. This dorsal ridge is therefore essentially comparable with the dipnoan muscular septum. New developments occur, however, in the engulfing of the proximal bulbar segment by the ventricle, its right to left expansion, the formation of the right ventral cavity and the appearance of the bulbo-ventricular ridge attached distally to proximal ventral endothelial cushion 4 *A*. These modifications result in a proportionate increase in size of both left and right ventricular cavities. In the lizard the bulbus is shortened and straightened and the spiral valve replaced by the spiral aortico-pulmonary septum, which, owing to the asymmetrical development of the right ventricle, only curves through an angle of 180°. The tissues of the distal bulbar segment are replaced by the non-muscular truncus arteriosus and this is correlated with the development of semilunar valves at the bases of the great vessels.

In the higher reptiles further modifications along the same lines occur. Here, owing to the increased right to left expansion of the right distal part of the ventricle, &c., the dorsal and bulbo-ventricular ridges intersect and join to form a continuous incomplete muscular interventricular septum which is finally completed round the right side of the right aorta by the proximal endothelial cushions of the aortico-pulmonary and aortic septa, and the fused auriculo-ventricular cushions, forming the pars membranacea septi. The bulbus cordis develops as in the lizard, but the aortic septum extends into the distal part of the right ventricle and then helps to close the interventricular foramen. The bulbus is finally replaced by the truncus

arteriosus and the great vessels are guarded by semilunar valves that are supported by a double muscular ring owing to the presence of muscle fibres in the border of the aortico-pulmonary septum.

The mammalian ventricle closely resembles that of the crocodile, only the right to left expansions of the distal ventricular segment and the accompanying left to right shifting of the auriculo-ventricular opening are more marked. The left common ventricle is asymmetrically divided into a smaller right and a larger left compartment and the right ventral cavity becomes part of the former. The left ventral part of the interventricular septum deviates to the left and is attached distally to the left proximal pillar of the aortico-pulmonary septum, that is to proximal bulbar ridge 4 *A*. All these details point to the mammalian interventricular septum being homologous with the reptilian. Here the interventricular foramen is closed by the aortico-pulmonary septum—the aortic septum having disappeared—and the auriculo-ventricular endothelial cushion, round the right side of the aorta, and the septum is complete. The bulbus cordis is developed as in the higher reptiles but the left aorta is not present, and the separation of the great vessels is completed by the lengthwise splitting of the aortico-pulmonary septum. The orifices of the pulmonary artery and aorta are guarded by semilunar valves.

Throughout the series of hearts examined the general trend would seem to be towards a final simplification of structure in the adult and to a concentration of muscular effort. As the bulbus cordis becomes more and more an efficient, more or less mechanical arrangement of tubes and valves, it progressively loses its muscular character and, at the same time, as the contractile character of the bulbus is lost, the powerfully muscular ventricle becomes proportionately increased in size.

BIBLIOGRAPHY.

[1] Born (G.) "Beitr., z. Entwickelungsgeschichte des Saeugetierherzens." Archiv. f. mikro. Anat., 1889, xxxiii, 284.

[2] Greil (A.). "Beitr., zur vergleichenden Anatomie und Entwickelungsgeschichte des Herzens und des Truncus Arteriosus der Wirbeltiere." Morphol, Jahrb., Leipzig, 1903, xxxi, 123.

[3] Hochstetter, (F.) "Die Entwickelung des Blutgefaess-systems." "Hertwig's Handbuch der Entwickelungslehre der Wirbeltiere," 1906, iii, Teile, 2, 21.

[4] Hochstetter (F.) "Beitr. zur Anatomie und Entwickelungegeschichte des Blutgefaess-systems der Krokodile." Reise in Ostafrika von Professor Dr. Alfred Voeltzkow. Wissenschaftliche Ergebnisse Heft I. Stuttgart, 1906.

[5] Lankester (E. Ray). "On the Hearts of Ceratodus, Protopterus and Chimaera, with an account of undescribed Pocket Valves in the Conus Arteriosus of Ceratodus and Protopterus." Trans. Zoolog. Soc., 1879, x, 493.

[6] Robertson (Jane I.). "The Development of the Heart and Vascular system of Lepidosiren paradoxa." Quart. Journ. Micr. Sc., 1914, lix, 53.

CARDIAC MALFORMATIONS IN WHICH THE GREAT EFFERENT VESSELS ARISE FROM THE RIGHT VENTRICLE.*

By JANE I. ROBERTSON.

(*From the Victoria Infirmary, Glasgow.*)

In the normal, fully developed human heart, the pulmonary artery and aorta are placed on the right and left sides respectively of the interventricular septum. The septum develops as a semilunar muscular ridge, extending across the fundus of the ventricle, its dorsal horn is attached along the ventricular surface of the fused auriculo-ventricular endothelial cushions towards their right margins and extends ventrally to the dorsal wall of the aorta; the ventral horn is attached round the left rim of the pulmonary artery and along the ventricular border of the aortico-pulmonary septum, extending therefore round the ventral and on to the right wall of the aorta (Fig. 1, *I*, *D.I.S.* and *V.I.S.*). The interventricular septum is thus placed obliquely from the right dorsally to the left ventrally, and, between its two horns, below the aortic orifice, is the gap of the interventricular foramen. The primitive common bulbar orifice is at first situated to the right of the developing septum and at this time the foramen serves to allow the blood from the left side of the heart to reach the bulbus. Later during development the rotation and expansion of the proximal bulbar segment from right to left and the corresponding left to right expansion of the auriculo-ventricular aperture, as well as the extension of the ventral horn of the interventricular septum from left to right along the margin of the aortico-pulmonary septum, all tend to bring the aortic channel directly over the interventricular foramen. The foramen is edged with endothelial tissue derived from the auriculo-ventricular and proximal bulbar cushions and ultimately it is closed round the right rim of the aorta by the fusion of its endothelial margins, thus forming the pars membranacea septi (Fig. 1, *I*, *P.M.*). The size of the pars membranacea varies very greatly in individual hearts owing to the varying degrees of development of the muscular elements of the septum.

There are thus various factors that help to bring about the completion of the interventricular septum round the right side of the aorta; first, the rotation of the dorsal and ventral cardiac limbs round one another which determines to a great extent the dorso-ventral relations of the various orifices at the base of the ventricles; second, the extension of the ventral horn of the interventricular septum from left to right along the ventricular border of the aortico-pulmonary septum; third, the normal development of the aortico-pulmonary septum itself, since the ventral horn of the inter-

* Published under the tenure of a Beit Memorial Fellowship.

ventricular septum is developed primarily in association with the left proximal pillar of the former septum and then extends along its base to the right pillar ; fourth, the shortest path from the right pillar of the aortico-pulmonary septum to the dorsal horn of the interventricular septum is, in normally developed hearts, round the right, not the left side of the aorta ; fifth, the

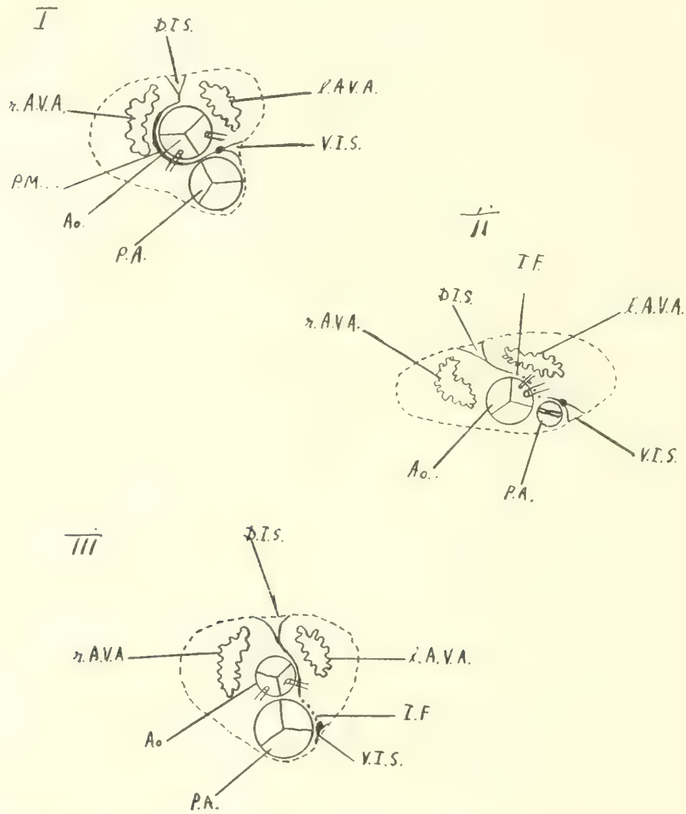


Fig. 1. Diagrams showing the relations of the apertures and chambers at the base of the heart. *I*, in the normal human heart ; *II*, in the malformed heart of a human fœtus ; *III*, in the malformed heart of a young pig. The junction of the aortico-pulmonary septum and of the ventral horn of the interventricular septum is indicated by a rounded knob.

Ao., Aorta ; *D.I.S.*, dorsal horn of the interventricular septum ; *I.F.*, interventricular foramen ; *l.A.V.A.*, left auriculo-ventricular aperture ; *P.A.*, pulmonary artery ; *P.M.*, pars membranacea septi ; *r.A.V.A.*, right auriculo-ventricular aperture ; *V.I.S.*, ventral horn of the interventricular septum.

presence of a continuous endothelial ring round the right side of the aorta ; sixth, to some little extent, perhaps, the left to right direction of the arterial blood current in the left ventricle. Any serious modifications of one or more of these factors would tend to interfere with the normal closure of the septum round the right side of the aorta.

The two specimens (Fig. 2 and 3) depicted here are both instances of the great efferent vessels arising directly from the right ventricle. The first specimen is from an eight months human fœtus that never breathed owing to a complete occlusion of the trachea; the second is from a week old pig that died of starvation due to a complete occlusion of the œsophagus. I am indebted to Dr. Anderson, pathologist to the Victoria Infirmary, Glasgow, for the former heart and also for the following brief notes.

"The body was that of a male child recently born and had reached eight months of intra-uterine life. The lungs were unexpanded, fleshy in appearance and of reddish colour—hydrostatic tests showed the child had not breathed. Examination of the upper respiratory tract showed a partial occlusion of the larynx at the position of the false cords (diaphragm aperture) and a complete occlusion of the trachea a little below the level of the larynx with a narrowing of the œsophagus at the same level. The thymus and thyroid were of large size but not abnormally large. The liver was normal in size, congested, of dark colour, but there were no lesions on section. The spleen was small and immature (about a third the usual size at such an age). Both kidneys were abnormally small, ill-defined and partially developed. There was a hypoplasia of the suprarenals. No malformation of the gastro-intestinal tract. Brain well developed but of usual soft character."

Of the second specimen I have no notes save of the total occlusion of the œsophagus (verified *post-mortem*) and the fact that during its brief existence the animal was persistently blue.

In the first specimen the heart as a whole is markedly flattened dorso-ventrally and also somewhat from right to left (Fig. 1, *II*). Both ventricles take part in the formation of the apex which has a slightly bifid appearance due partly to the large size of the left coronary artery in the interventricular furrow. The large aorta is placed on the right alongside the very small pulmonary artery (Fig. 1, *II*, Fig. 2, *Ao.* and *P.A.*), and the right ventricle forms a prominent shoulder at the base of the heart. The left auricle is small and thin-walled and is divided by the bulging of the persistent left superior vena cava into a right pulmonary and a left appendicular portion. The right auricle is large and muscular and receives the left, right and inferior venæ cavæ.

Internally the following malformations are manifest. The interauricular septum is represented merely by one or two irregular little tags; both the auriculo-ventricular openings are compressed laterally and directed obliquely from right to left (Fig. 1, *II r.* and *l.A.V.A.*), the right aperture has only two valves, a right and a left one, instead of the usual three, thus resembling the condition in the hearts of some mammalians as the otter and the kangaroo. There is no marked disproportion in size between the right and left ventricles but they are both flattened dorso-ventrally and the latter is distinctly dorsal to the former (Fig. 1, *II*). The interventricular septum is placed much more obliquely, from the right dorsally to the left ventrally, than usually and its normal curve into the right ventricle is lacking (*cf.*

Fig. 1, *I* and *II*). From its attachment between the two auriculo-ventricular openings (Fig. 1, *II*, *D.I.S.*) the septum passes ventrally and to the left on to the left rim of the pulmonary artery (Fig. 1, *II*, *V.I.S.*) below the left rim of the aorta. Where it passes below the aorta there is a considerable interventricular foramen (Fig. 1, *II*, Fig. 1, *I.F.*) that allows the blood from the left side of the heart to reach the aorta and pulmonary artery on the right. The pulmonary artery is abnormally small and at its ventricular end is situated more to the left of the proportionately larger aorta (Fig. 1, *II*, Fig. 2, *Ao.* and *P.A.*) than is usual. Beyond this disproportion in their relative sizes, however, and the modification of their relative points of origin from the ventricle, the two great vessels present no further abnormalities. The aorta is provided with three semilunar valves, one right, one left dorsal and one right ventral (Fig. 1, *II*, *Ao.*) and both the coronary arteries arise from the vessel wall external to the left dorsal cusp (Fig. 1, *II*, Fig. 2, *P.A.*). The left artery is distinctly the larger and seems to supply most of the ventral and dorsal surfaces of both ventricles as well as the interventricular septum. The right artery is much smaller and passes dorsal to the root of the aorta on to the right shoulder of the right ventricle, where it is distributed dorsally and ventrally. The stenosed pulmonary vessel is only furnished with two semilunar valves, a left dorsal and a right ventral one respectively (Fig. 1, *II*, Fig. 2, *P.A.*). There is no defect in the aortico-pulmonary septum the right free segment of whose proximal border is directed from the left and dorsally to the right and ventrally between the two vessels. It is to be noted that here, as in the crocodile (see this *Journal*, p. 87), the free border of the aortico-pulmonary septum, that is, that part of it along which the ventral horn of the ventricular septum has not extended, contains muscular tissue (Fig. 2, *S.Ao.P.*). This muscular bridge in the aortico-pulmonary septum is continuous with the ventral ventricular septum on the one hand and on the other with the ventral wall of the ventricle. As in the crocodile, therefore, the proximal pulmonary aperture is surrounded by a muscular ring. The trabecular character of the inner surface of the ventricular wall is very marked in both chambers.

In this specimen it would seem as though the persistence of the left superior vena cava had had an inhibitory influence on the expansion and muscular development of the left auricle and so indirectly brought about the abnormal position of the aorta on the right of the interventricular septum. The left auricle being, so to speak, out of commission, the right auricle has hypertrophied to deal with the adequate propulsion of the blood into both ventricles; it is also possible that some of its increase in size and muscularity may be due to regurgitation from an overloaded right ventricle. With the over development of the right auricle is probably associated the general right to left development of the heart as a whole, and this extra amount of torsion added to the normal right to left expansion of the proximal bulbar segment, has carried the pulmonary artery abnormally far to the left of the aorta. That is to say, the proximal left and right pillars of the aortico-pulmonary

septum were carried more to the left and right respectively than usual, and therefore the ventral horn of the interventricular septum, which as has been shown (see this *Journal*, p. 87) is always associated with the point of insertion of the left pillar, lies correspondingly further to the left (Fig. 1, *II*, *V.I.S.*). In this heart the ventral horn of the interventricular septum did not extend along the proximal border of the aortico-pulmonary septum which is directed practically dorso-ventrally, but merely maintained its attachment to the left pillar. Again, owing to the exaggerated right to left development of the whole heart, the aorta was never placed sufficiently to the left to lie over the interventricular foramen which therefore remained on the left of the vessel and was probably kept patent by the stream of blood from the left ventricle. For similar reasons the dorsal ventricular septum came into relation with the left, instead of the mid-dorsal, wall of the aorta (Fig. 1, *II*, *D.I.S.* and *Ao.*). In this heart there is no pars membranacea septi at all, the interventricular foramen here having nothing to do with that structure which is formed from endothelial tissue that is continuous round the right, not the left, side of the aorta. It is of interest to note that had the ventricular septum closed in this specimen, the shortest, and therefore the most probable, path for it to have taken, would have been round the left not the right side of the aorta (Fig. 1, *II*, *I.F.*). The degree of stenosis of the pulmonary artery seems primarily due to the malposition of the aortico-pulmonary septum leading to an asymmetrical division of the bulbus cordis into a small pulmonary and a large aortic stem. The increased pressure offered by the stenosed pulmonary artery would tend to maintain the disproportion in size between the two vessels, the greater volume of blood passing along the line of less resistance offered by the widely patent, large aorta. In this heart, owing to the unusually dorso-ventral position of the aortico-pulmonary septum at its proximal end, the normal torsion of the great vessels round one another is considerably diminished.

In the second specimen the heart as a whole presents no strikingly unusual characteristics. There is no distinct ventral interventricular furrow and no indication externally as to which chamber forms the apex. Internally the following conditions are apparent. Except for a large patent foramen ovale there are no auricular malformations. The left auricle is not markedly smaller than the right, but the left ventricle is considerably smaller than the corresponding right chamber, and the apex of the heart is formed entirely by the latter. The auriculo-ventricular apertures are normal. The pulmonary artery is proportionately much wider than the unusually narrowed aorta (Fig. 1, *III*, Fig. 3, *Ao.* and *P.A.*), but otherwise the two vessels present no further abnormalities than the position of the aorta on the right of the interventricular septum (Fig. 1, *III*, Fig. 3, *Ao.*). The coronary arteries are in their normal situations. The interventricular septum is straighter and placed more directly dorso-ventrally than usual, it passes from the dorsal wall of the ventricle round the left rim of the aorta, to which it has a direct muscular attachment, and on to the left rim of the

pulmonary artery. Immediately below the latter vessel, however, the ventral horn of the septum is pierced by a large oval foramen reaching some little distance along the ventral wall of the heart (Fig. 1, *III*, Fig. 3, *I.F.*). This aperture leaves a bridge of the ventral septum extending along the left rim of the pulmonary artery; that is, continuous with the dorsal septum round the left rim of the aorta. The aortico-pulmonary septum shows no malformation, but the ventral horn of the ventricular septum does not extend along its proximal border but passes, as described, to the left along the great vessels. The free border of the aortico-pulmonary septum is also muscular in this case, but it is very much more powerfully developed than in the first specimen (*cf.* Fig. 2 and 3, *S.Ao.P.*).

It is difficult to account satisfactorily for the arrangement of the septum and great vessels in the second specimen. The disproportion in size of the two ventricles may possibly be attributed to the early and permanent presence of the ventral interventricular foramen which allowed of an unusually easy passage of the blood from the left to the right side of the heart. This, again, may have led to the abnormal size of the pulmonary vessel and to the stenosis of the aorta, and this in turn to the inclusion of the aorta in the right ventricle. Here, as in the first specimen, the shortest, and therefore apparently the more eligible, path for the fusion of the two septal horns was from the dorsum of the aorta round its left side and on to the left side of the pulmonary artery. The formation of this shorter left path has been largely due to the relatively disproportionate sizes of the two great vessels (Fig. 1, *III*, *Ao.* and *P.A.*). In this specimen the normal interventricular foramen between the dorsal and ventral horns has been closed by muscular tissue attached directly to the left rim of the aorta, there is no pars membranacea septi, partly probably because there is no available endothelial tissue in this region. The existing abnormal interventricular foramen (Fig. 3, *I.F.*) is due to an early perforation in, not to an absence of, the ventral interventricular septum.

Conclusions.

The two specimens examined present practically different degrees of the same ventricular abnormality, based apparently on quite different causal conditions and that would have, probably, resulted in widely different degrees of circulatory disturbance. It is impossible to say whether the condition in the first specimen was compatible with independent existence or not. The pig survived well enough for a week, though whether, had it had the use of its digestive tract, it would ever have achieved market condition is another matter. The preceding notes would seem to point to the conclusion that the completion of the interventricular septum round the right or the left sides of the aorta depends ultimately on which of them affords the shorter path of contact between its dorsal and ventral horns.

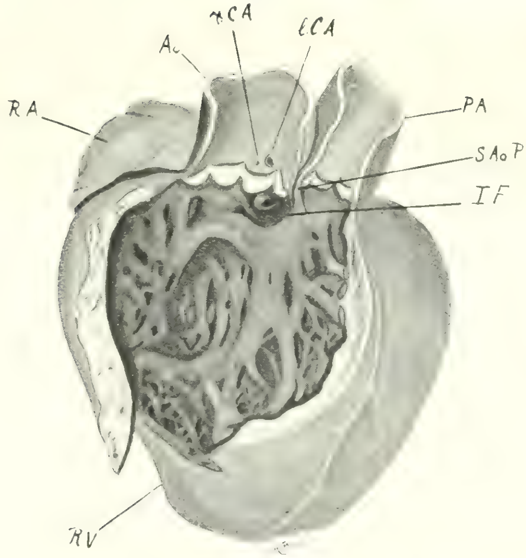


Fig. 2. Drawing of the malformed human fœtal heart. The outer wall of the right ventricle has been opened and drawn to the right to expose the interior of the chamber.

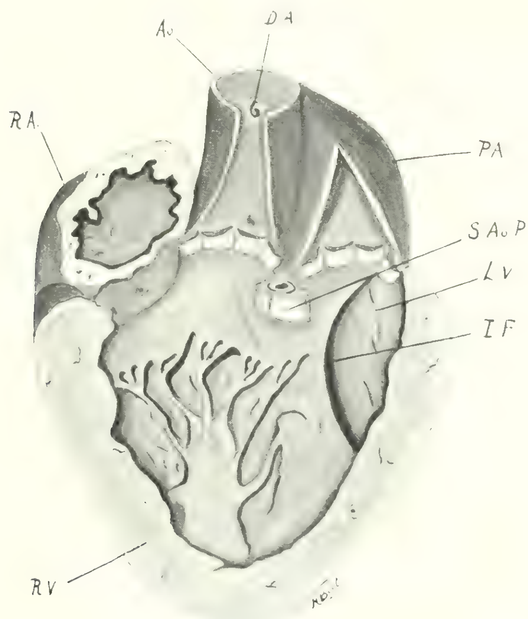


Fig. 3. Drawing of the malformed heart of a young pig. The outer wall of the right ventricle has been cut away to expose the interior of the chambers. *Ao.*, aorta; *D.A.*, ductus arteriosus; *I.F.*, interventricular foramen; *l.C.A.*, left coronary artery; *L.V.*, left ventricle; *P.A.*, pulmonary artery; *R.A.*, right auricle; *r.C.A.*, right coronary artery; *R.V.*, right ventricle; *S.Ao.P.*, aortico-pulmonary septum.

ON THE VARIABILITY OF THE SIZE OF THE PULSE IN CASES OF AURICULAR FIBRILLATION.

By W. EINTHOVEN and A. J. KORTEWEG.

(*From the Physiological Laboratory, Leyden.*)

Introductory Remarks.

By means of electrocardiography Rothberger, Winterberg and Lewis have shown that with patients who show Mackenzie's "nodal rhythm" or Hering's "pulsus irregularis perpetuus" the auricles fibrillate. Thereby they have at the same time shown the real cause of the irregularity of the pulse in these patients. The stimulus is conveyed along the normal path, viz., along the "auriculo-ventricular node of Tawara" and the "junctional bundle of Kent and His" from the auricles to the ventricles, but the separate contraction of each of the many auricular muscular fibres cannot produce a ventricular contraction. Lewis[5] says: "The bundle transmits only certain of those impulses which are showered promiscuously upon the small area abutting upon the upper termination (the auriculo-ventricular node). Contraction waves flowing in several directions towards the narrowing channel, which forms the impulse inlet to the ventricle, are eventually transmitted in a single direction along the usual path and confusion of impulse transmission in the bundle itself is avoided. From the turmoil in the auricle a rapid and haphazard succession of waves escape, and, escaping, are confined to a single course, the boundaries of which are parallel. Thus two facts are explained: first, the absolute irregularity of the ventricular responses to a fibrillating auricle, and second, the inability of the fibrillation to transmit itself from upper to lower chamber."

This explanation, which agrees with that of Rothberger and Winterberg and is now generally accepted, is perfectly satisfactory.

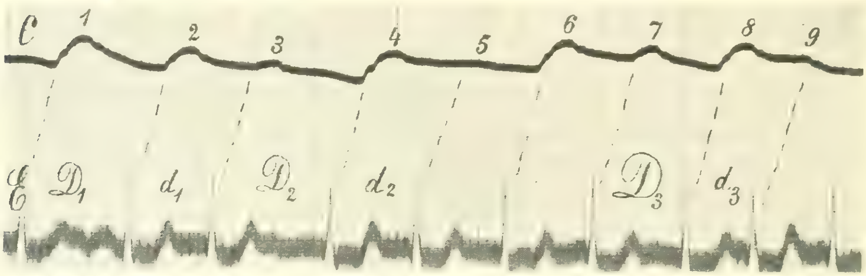
At the same time it only refers to part of the peculiar phenomena that are observed in the arterial pulse, as this is not only "irregularis" but also "inæqualis." Whereas the above deals only with the irregularity of the pulse, the "inæqualis," *i.e.*, the inequality of the size of the pulse, requires further consideration, and this phenomenon in particular is the subject of the present article.

Speaking generally, the content of the left ventricle must be considered as one of the factors that influence the size of the pulse. If a well-filled ventricle empties itself into the aorta, the pulse, *cæteris paribus*, will be larger than when the ventricle at the beginning of the systole contains only a small amount of blood. If there has been a long pause between two systoles, enabling the ventricles to become well filled with blood, then there is in

general a probability that the ensuing pulse will be large. And *vice versa*, when the cardiac pause has been short the likelihood of a small pulse is greater.

The above shows that one of the causes of the variable size of the pulse must lie in the irregular working of the heart itself. It is a fact that with patients suffering from auricular fibrillation often a large pulse follows a long ventricle pause, and a small pulse a short pause.

As an example of this we reproduce in Fig. 1 the E.K.G. by lead *II* of a female patient suffering from auricular fibrillation.



Lead II.* Fig. 1.

The connection between the size of the pulse and the preceding cardiac pause is shown here with particular clearness every time that a short pause immediately follows a longer one, or immediately precedes a longer one. After the long pauses, D_1, D_2 and D_3, the large pulses 2, 4 and 8 appear, while the short pauses d_1, d_2 and d_3, are followed by the small pulses, 3, 5 and 9.

But the content of the ventricles is not the only cause which influences the size of the pulse. There must be other influences at work. If the size of the pulse were determined only by the duration of the preceding diastole it would show the phenomenon—which we have described above only as frequently occurring—regularly and without exception. Regularly a large pulse would follow a long diastole and a small pulse a short one.

This regularity, however, is not found in patients with auricular fibrillation. Very often the other factors which influence the size of the pulse predominate ; in fact this is so much the case, that Lewis[5] regards it as one of the characteristics of the state of auricular fibrillation : "The second criterion consists in the absence of a definite and continued relationship between the strength of a beat and the length of the pause which precedes it. A strong beat may follow a short pause, and a weak beat may succeed a long pause."

* In all photograms we have Absc. 1 div. = 0·04 sec. ; Ordin. 1 div. = 10^{-4} volts.

Many other writers arrive at the same conclusion. Theopold,[7] for instance, says that in Arrhythmia perpetua the duration of the systole and diastole is quite irregular, and that weak and strong pulses continually and quite arbitrarily alternate with each other.

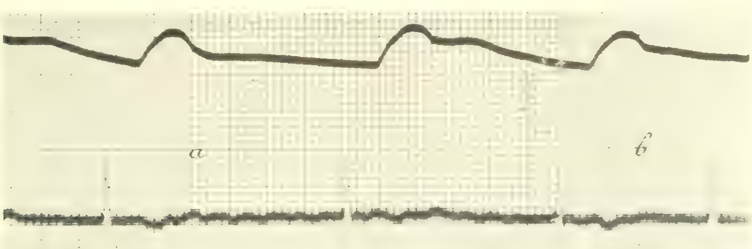
Wenckebach[8] also, in the treatment of his "Fälle regelloser Herztätigkeit," repeatedly points out the incongruity which is so often found between the duration of the diastole and the size of the pulse that follows it.

All this brings us to the question: "What are the circumstances that have so strong an influence upon the pulse that the effect of the preceding pause is no longer immediately perceptible?"

We look for the answer principally in the size of the preceding pulse-wave. This is the factor to which we shall specially direct our attention in the following pages.

Results of measurements.

In Table I A the results are given of a number of measurements taken on seven photographic plates. These are all taken from another patient who has been suffering for many years from insufficiency and stenosis of the valvula mitralis. In Fig. 2 a small part of one of the photograms is given. The carotid pulses appear as fairly large waves. The fibrillations of the auricle are irregular.



Lead III. Fig. 2.

While the waves are clearly visible in some parts of the E.K.G., *e.g.*, at *a*, at other places, *e.g.*, at *b*, they are almost entirely absent. As in all cases of auricular fibrillation, peak *P* is absent. The table gives the height of the pulse-waves, and the duration of the cardiac periods preceding them, and it is not difficult to conclude from the figures given that there is a connection between the two groups of values. This relation becomes even clearer when the results in Table I A are represented graphically, as is done in Fig. 3, I A. In a system of co-ordinates the heights of the pulse-waves are set out as ordinates and the duration of the preceding heart periods as

TABLE I A.

AMPLITUDE OF THE PULSE-WAVE, V.D.L.

Length of the preceding heart period in sec..	Amplitude of the pulse-wave in mm.
0·55 — 0·58	2·3
0·59 — 0·62	2·4 - 2·4 - 1·8
0·63 — 0·66	2
0·67 — 0·70	3·3 - 3 - 3 - 3 - 2·9 - 2·9 - 2·8 - 2·8 - 2·6 - 2·4
0·71 — 0·74	3 - 2·2 - 2
0·75 — 0·78	3 - 2·6 - 2·6
0·79 — 0·82	3·6 - 3·3 - 2·6 - 2·4
0·83 — 0·86	4·3 - 4·2 - 3·6 - 3·5 - 3·4 - 3·3 - 3·2
0·87 — 0·90	4·7 - 4·5 - 3·2
0·91 — 0·94	4·2 - 4·2 - 4
0·95 — 0·98	5·2 - 4·3 - 4·2 - 4·2 - 4·1 - 4 - 3·7
0·99 — 1·02	4·5 - 4·4 - 4·3 - 4 - 3·8
1·03 — 1·06	4·2
1·07 — 1·10	5·4 - 5 - 4·6
1·11 — 1·14	5 - 4·6
1·15 — 1·18	4·3
1·19 — 1·22	5
1·23 — 1·26	5·8
1·27 — 1·30	5·6 - 4·9
1·31 — 1·34	5·3
1·35 — 1·38	
1·39 — 1·42	
1·43 — 1·46	
1·47 — 1·50	
1·51 — 1·54	5·8 - 5·1
1·55 — 1·58	
1·59 — 1·62	5·8

abscissæ. Each pulse is represented by a point. It will be seen that in general the large pulses correspond to long preceding heart periods, and the small pulses follow short periods.

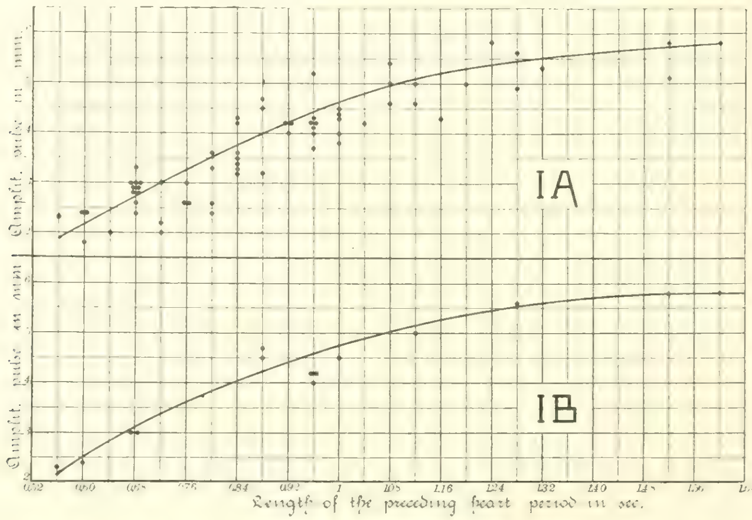


Fig. 3, I A and I B.

The curve, which in the diagram is drawn as uniformly as possible through the points, shows approximately the way in which the two groups of values would seem to be connected.

Owing to the small number of pulses measured, it was not possible to exclude all arbitrariness in drawing the curves. If the points were more numerous the drawing of the line would be easier, and if we had some thousands of pulses at our disposal the form of the line could be drawn with a probability bordering upon certainty.

Pursuing our argument, if the size of the pulse were determined entirely by the duration of the preceding heart period, all points would lie precisely upon the line drawn. This, as can be seen, is far from being the case. Most of the points lie comparatively far below or above the line, from which it necessarily follows that besides the length of the preceding heart period there are other factors which influence the size of the pulse. These factors make themselves felt at entirely irregular moments, and cause now an enlargement and now a diminution of the pulse. The more they are eliminated the nearer the points will come to the line, until by the elimination of all additional factors the points, as already remarked, would fall without exception exactly on the line.

TABLE I B.

AMPLITUDE OF THE PULSE-WAVE, V.D.L.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm..					
	1 - 1·9	2- 2·9	3 - 3·9	4 - 4·9	5 - 5·9	6 - 7
	Amplitude of the pulse-wave in mm..					
0·55 — 0·58		2·3				
0·59 — 0·62		2·4		1·8 - 2·4		
0·63 — 0·66				2		
0·67 — 0·70	3·3	3 - 3	2·4-2·8-2·9-3	2·8 - 2·9	2·6	
0·71 — 0·74				2·2	3	2
0·75 — 0·78			3	2·6	2·6	
0·79 — 0·82				3·3	2·4-2·6-3·6	
0·83 — 0·86	4·3 - 3·5		3·3 - 4·2	3·6	3·2 - 3·4	
0·87 — 0·90		4·5 - 4·7	3·2			
0·91 — 0·94			4·2	4 - 4·2		
0·95 — 0·98		4·4·2-4·2	4·3 - 5·2	3·7 - 4·1		
0·99 — 1·02		4·5	3·8-4·3-4·4		4	
1·03 — 1·06			4·2			
1·07 — 1·10			5·4	4·6 - 5		
1·11 — 1·14		5		4·6		
1·15 — 1·18			4·3			
1·19 — 1·22					5	
1·23 — 1·26			5·8			
1·27 — 1·30		5·6		4·9		
1·31 — 1·34			5·3			
1·35 — 1·38						
1·39 — 1·42						
1·43 — 1·46						
1·47 — 1·50						
1·51 — 1·54		5·8		5·1		
1·55 — 1·58						
1·59 — 1·62		5·8				

In order to investigate whether the height of the preceding pulse-wave is one of the factors above mentioned, we proceed in the following way. We arrange the figures in the second column of Table I A, both according to the length of the preceding heart period and to the height of the preceding pulse-wave. This has been done in Table I B. In the first verticle column the length of the preceding heart period is given ; in the second column the size of the pulse which occurs after a pulse the height of which is between 1 and 1·9 mm. ; in the third column the size of the pulses which appear after a pulse the height of which lies between 2 and 2·9 mm., &c..

Let us consider the figures of one of the columns, *e.g.*, of the third column, which contains the heights of all pulses which occur after a pulse of 2 to 2·9 mm.. These figures are represented as points in the system of co-ordinates of diagram I B. The diagram is arranged in exactly the same way as Fig. 3, I A, and therefore hardly needs any further explanation. The points indicate all the pulse-heights that are given in the third column of Table I B, and the curve is drawn as far as possible through these points, while keeping to a simple form.

It will be seen that in Fig. 3, I B, the points in general lie less far from the line than in Fig. 3, I A. A comparison of the amount of the mean deviation which is found in each of the figures would show how great the influence of the height of the preceding pulse-wave is. In order to arrive at a more definite result we might apply the methods here which are usual in the theory of probability. But these are somewhat elaborate and rather beyond our scope. For the sake of simplicity we have confined ourselves to the following calculation.

The distance from a point to the place where its ordinate cuts the curve is the deviation between the height of the theoretically determined pulse and an actual one. If we call this deviation a and the number of pulses n, the mean deviation of a pulse-height is $W = \frac{\Sigma a}{n}$, in which Σa represents the sum of the deviations, all taken positively.

The calculation is very simple and at the same time quite sufficient for our purpose.

In Fig. 3, I A, the value of Σa is 24·6 mm., while the number of pulses is $n = 65$. From this it follows that the mean deviation of a pulse-height is $W_{IA} = \frac{24 \cdot 6}{65} = 0 \cdot 38$ mm..

In Fig. 3, I B, the mean deviation is found to be $W_{IB} = \frac{3 \cdot 05}{14} = 0 \cdot 22$.

We see thus that W_{IB} is smaller than W_{IA}. From this fact we may draw the conclusion with a certain amount of probability that the height to which a pulse will develop is dependent upon the height of the preceding pulse-wave. If our calculation of W_{IA} and W_{IB} were based upon measurement of a larger number of pulses, our conclusion would be more firmly established, and if the same result were obtained from measurements on many thousands of pulses, our conclusion might lay claim to a probability bordering upon certainty.

From the circumstance that W_{IB} is more than zero we may conclude that the duration of the preceding heart period and the size of the preceding pulse-wave are not the only two factors which determine the size of the coming pulse, a conclusion which is, moreover, in complete accordance with the prevailing opinions in physiology and pathology.

In Table II we have put together similar data from still another patient. In the photogram 4 we see the carotid pulse and the E.K.G. of the patient by lead *I*, in photogram 5 by lead *II*. The usual characteristics of auricular fibrillation are all present.

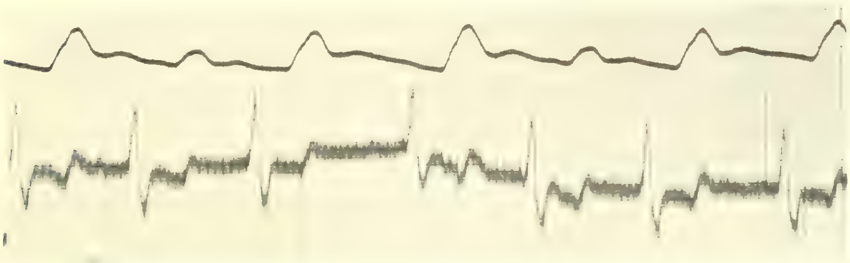


Fig. 4.

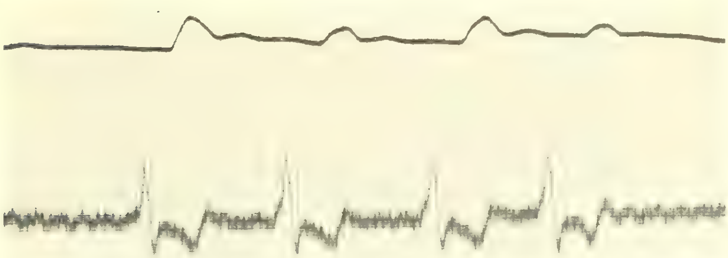


Fig. 5.

The data of Table II are graphically represented in the diagrams II A and II B, which are constructed in the same way as the previous ones: Fig. 6, II A, includes all the pulses from the table, while Fig. 6, II B, contains only those pulses which follow a pulse-wave of the height of between 2 and 3·9 mm.. The mean deviation of a pulse-height from the curve in Fig. 6, II A, is $W_{IIA} = \frac{8 \cdot 2}{20} = 0{\cdot}41$ mm.; in Fig. 6, II B, it is $W_{IIB} = \frac{1 \cdot 4}{7} = 0{\cdot}20$ mm..

Here we obtain the same result, viz., that the mean deviation which an actual pulse shows from the theoretically determined one is less when the height of the preceding pulse-wave remains confined within certain limits.

TABLE II.

AMPLITUDE OF THE PULSE-WAVE, V.K.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm..				
	1 - 1·9	2 - 2·9	3 - 3·9	4 - 4·9	5 - 5·9
	Amplitude of the pulse-wave in mm..				
0·59 — 0·62	2·9		1·4	1·3	
0·63 — 0·66			1·9	1·5 - 1·6	
0·67 — 0·70					
0·71 — 0·74				2·1	
0·75 — 0·78		3·2			
0·79 — 0·82					
0·83 — 0·86					
0·87 — 0·90					
0·91 — 0·94		3·8		3·2	
0·95 — 0·98	5			3·2	
0·99 — 1·02			4·2		3·7
1·03 — 1·06	4 - 4·3				
1·07 — 1·10			5		3·8
1·11 — 1·14	4·3				
1·15 — 1·18					
1·19 — 1·22					
1·23 — 1·26					
1·27 — 1·30					
1·31 — 1·34			4·5		

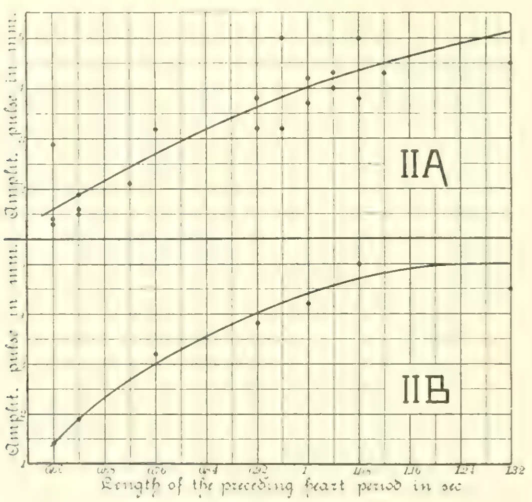


Fig. 6. II A and II B.

Table II refers to a period in which the heart frequency of the patient was about 84 per minute. Later on other curves were taken from the same patient, when the heart frequency was only 62 per minute. These curves

TABLE III.

AMPLITUDE OF THE PULSE-WAVE, V.K.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm.. 1 - 1·9	2 - 2·9	3 - 3·9	
	Amplitude of the pulse-wave in mm..			
0·67 — 0·70		1·6		
0·71 — 0·74				
0·75 — 0·78		2·2		
0·79 — 0·82				
0·83 — 0·86		2·2 - 2·4		
0·87 — 0·90				
0·91 — 0·94			2·3 - 2·5	
0·95 — 0·98		2·6 - 2·8 - 3	2·9 - 3	
0·99 — 1·02			2·7 - 2·9	
1·03 — 1·06	3·6		3	
1·07 — 1·10		3	2·7	
1·11 — 1·14			2·9 - 3·4	
1·15 — 1·18		3		
1·19 — 1·22			3	
1·23 — 1·26		3·3 - 3·7	3·5	
1·27 — 1·30				
1·31 — 1·34				
1·35 — 1·38				
1·39 — 1·42		3·8		

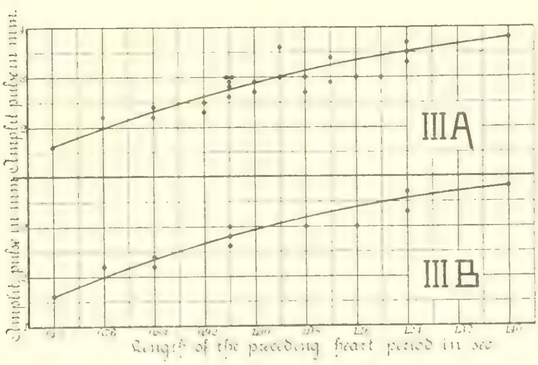


Fig. 7. III A and III B.

have supplied the data for Table III and diagrams III A and III B. The mean deviation of the actual pulse-heights from the curve is :

$$W_{IIIA} = \frac{4{\cdot}60}{25} = 0{\cdot}18 \text{ mm.}$$

$$\text{and } W_{IIIB} = \frac{1{\cdot}70}{12} = 0{\cdot}14 \text{ mm..}$$

The result is again similar to the previous ones.

Below we reproduce four more of our tables, which are selected because they contain a comparatively large number of figures. It appears to us unnecessary to construct curves for each of the tables. A glance at the figures in each table is sufficient to confirm the relationship which we wish to suggest.

It can easily be seen that in each table the pulse-heights, which are arranged in a vertical column, *as a rule** increase from above downwards, while those which are in a horizontal row as a rule* decrease from left to right. Although we cannot test the relation in question by the thousands of pulses that we should wish to measure, yet by the evidence produced above we may take it as practically demonstrated that the height of a given pulse-wave is to a certain extent dependent upon both the duration of the preceding cardiac pause and the height of the preceding pulse.

Tables IV and V are taken from a patient from whom in Fig. 8 and 9 we reproduce the carotid pulse and E.K.G..

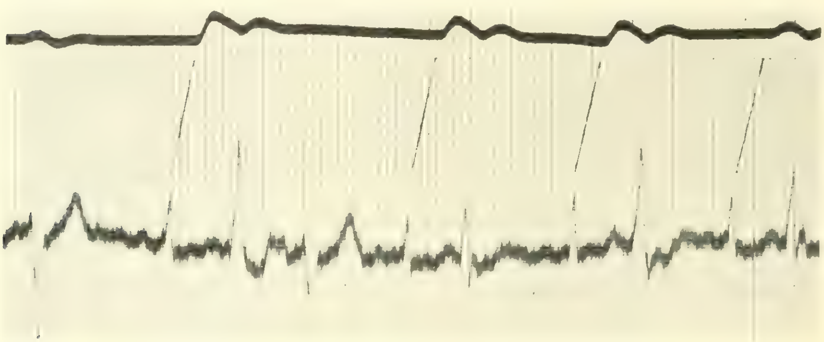


Fig. 8.

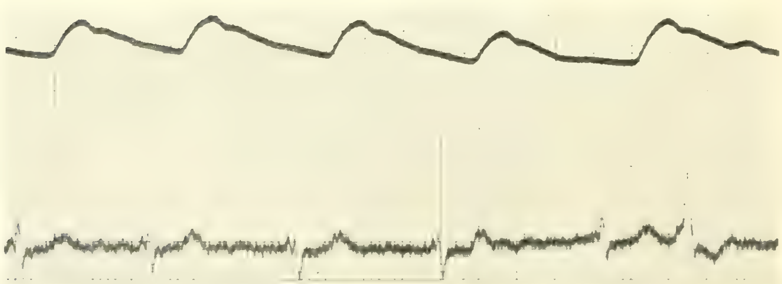


Fig. 9.

The auricular fibrillation is clearly shown in the curves.

---

* Emphasis should be laid upon "as a rule." As the number of pulses at our disposal is comparatively small, it may be possible according to the laws of probability—and it does actually occur in our series of figures as an exception—that W_B is found greater than W_A in given nstances.

TABLE IV.

AMPLITUDE OF THE PULSE-WAVE. W.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm..					
	0	0·1 - 0·9	1 - 1·9	2 - 2·9	3 - 3·9	4-4·9
	Amplitude of the pulse-wave in mm..					
0·31 — 0·34	1·2 (after 2 × 0)		0	0	0	
0·35 — 0·38	0 - 1·2	0·3		0	0 - 0 - 0	0
0·39 — 0·42	0·9	1·2		0·3 - 0		0
0·43 — 0·46	2·6-2·4-2·5-2·3	2	0·3 - 1·7 - 2	0·1 - 0·8 - 0·7		
0·47 — 0·50	2·4 - 2 - 2·5	3 - 2·7 - 2·2	2·6 - 3·8 - 3·8	1·8 - 0 - 0	0	
0·51 — 0·54	2·6			2·1 - 0·2	0	0
0·55 — 0·58	3·8 - 3·4			3·2 - 2·6	1·7 - 1·5 - 0·2	
0·59 — 0·62						
0·63 — 0·66	4·2			3·3	2·1	
0·67 — 0·70				3·9 - 3·3 - 3·3		
0·71 — 0·74		4·4 - 4·6				

TABLE V.

AMPLITUDE OF THE PULSE-WAVE. W.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm..							
	0	0·1-0·9	1 - 1·9	2 - 2·9	3 - 3·9	4 - 4·9	5 - 5·9	6-6·9
	Amplitude of the pulse-wave in mm..							
0·35 — 0·38			1·2	0·9	0·3		0·4	
0·39 — 0·42		0·8	2·2	1·8	1·2-0·3	0·8	0·3-0·1	0
0·43 — 0·46		3·6-2·4-2·1	2		1·5-1·3-0·8		0·2	
0·47 — 0·50		3·7-2·4	2·3					
0·51 — 0·54		3·8-2·5	3·3-2·5	3·5-3·2·3	3·8-1·7-1			
0·55 — 0·58		3·8-3·7	4·5-3·9-2·5	4·4-3·6		0·2	0·4-0·3	
0·59 — 0·62		6·1	3·9	1·6	4·4-1·9		2	1·1
0·63 — 0·66			5		3·1			
0·67 — 0·70	5·7			3·6		4·3		
0·71 — 0·74		5·4		4.-		5·2	2·7	
0·75 — 0·78		6·6-5·4	5·9		5·-	4·3-3·7-3·4		
0·79 — 0·82				4·9				
0·83 — 0·86					5·6			

TABLE VI.

AMPLITUDE OF THE PULSE-WAVE, V.G.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm..							
	0	0·1-0.9	1-1·9	2-2·9	3-3·9	4-4·9	5-5·9	6-6·9
	Amplitude of the pulse-wave in mm..							
0·31 — 0·34	0 - 0							
0·35 — 0·38	0·7-0·8-0·9	0-0-0·7-0·7-1	0-0·1-0·6	0-0-0·1-0·8	0 - 0			
0·39 — 0·42		1·3	1·2	0·1			0	
0·43 — 0·46	0·7	1·7-1·9-2·6	1·3			0 - 0		
0·47 — 0·50	2 - 3·3		1·9		0 - 0·3			
0·51 — 0·54		4·3					0·7	
0·55 — 0·58	3	3·6		1·3 - 1·5				
0·59 — 0·62				2	2·6	2		1·5
0·63 — 0·66	5		4·3					
0·67 — 0·70		3·1 - 3·2	2·6 - 2·5		3·2 - 1·8		1·5	
0·71 — 0·74	3·9		2·3	3·5	2·1	2·1	1·2	
0·75 — 0·78		4·8		4·4	2·9			
0·79 — 0·82	3·8							
0·83 — 0·86					6	3 - 5·1		
0·87 — 0·90								
0·91 — 0·94	4·7 - 5·3		5·3					

TABLE VII.

AMPLITUDE OF THE PULSE-WAVE, V.G.

Length of the preceding heart period in sec..	Amplitude of the preceding pulse-wave in mm..						
	0 - 0·9	1 - 1·9	2 - 2·9	3 - 3·9	4 - 4·9	5 - 5·9	6 - 6·9
0·31 — 0·34	0 - 0 - 0						
0·35 — 0·38				0 - 0 - 0			
0·39 — 0·42		0·1		0	0		
0·43 — 0·46							
0·47 — 0·50	3·9			0·2	2·9	3·4	
0·51 — 0·54				1·5			3·3
0·55 — 0·58				4·6 - 5·4			4·3
0·59 — 0·62	4·8 - 5				3·2 - 3·7		
0·63 — 0·66					2·9 - 3·3		
0·67 — 0·70	5·4				3·7	3·5 - 4·4	
0·71 — 0·74	6·6			3·9 - 4·3	4	4·7	4·1
0·75 — 0·78			3·6	3·4	4		
0·79 — 0·82	6·2				3·8-4·7-4·8	4·3	
0·83 — 0·86			5·1		4·1 - 6		
0·87 — 0·90							
0·91 — 0·94				4·9	4·5		

We may here add a few remarks in explanation of the tables.

In many places the pulse-height will be seen to be marked as being zero. This has been done wherever a heart contraction is registered by means of the E.K.G., without being followed by a visible pulse-wave. A pulse zero is only a special case, which fits entirely in the scheme of our observations and measurements.

The pulse beats, which, as shown by the form of E.K.G., are caused by atypical heart contractions, are marked with an asterisk. One might be tempted to decide, with the help of the method we have used, whether these heart contractions are of equal value with ordinary typical ones or not. But while some pulses from atypical contractions are smaller than might be expected under the same circumstances from typical ones, with a few others the reverse is the case. In order to eliminate all casual influences which act irregularly we should need to have a very great number of atypical and typical heart contractions, many more than we have at present at our disposal. This method is therefore less to be recommended than a previous one which we have made use of,[2] and by which we came to the conclusion that many atypical contractions were hardly if at all inferior to ordinary typical ones in their effect.

Further speculations concerning the origin of the unequal pulse-heights.

In our tables and in the constructions of our curves instead of the duration of the preceding diastole, we have taken the duration of the preceding heart period into consideration. This has been done for two reasons; in the first place, because the E.K.G. does not always enable us to determine the separate duration of the systole and diastole with sufficient accuracy.

This is particularly the case with patients suffering from auricular fibrillation, in whom the exact form of the peak T is often difficult to recognise owing to the superposition of the irregular auricular wavelets. On the other hand, the measurement of the duration of the whole period presents no difficulties. In the second place, because the venous blood flows towards the heart, even during the ventricular systole, which circumstance we have to take into account.

The venous blood during the diastole does not flow with a constant rapidity towards the ventricles. The auricles drive it forward rhythmically by their contractions. Whenever the auricles work irregularly, as in the case with patients with fibrillation, it may very well occur that during one diastole only a little and during another diastole of equal length considerably more blood is sent into the ventricles. This circumstance has been particularly emphasised by Cushny and Edmunds.[1]

There are many investigators who endeavour to explain the irregular size of the pulses by causes that lie in the chambers of the heart itself. Wenckebach,[2] for instance, mentions the possibility that negatively inotrope influences might diminish the contractability of the heart. Hoffmann[3] suggests—in his explanation of the pulsus alternans—that the heart, after a powerful contraction which causes a large pulse, would not be able immediately to act again equally vigorously, and Cushny[1] points out the possibility of yet another factor, the incomplete diastole of the ventricles. Finally it might be imagined that variations in the duration of the systole contribute to make the size of the pulse vary.

But the results of the electrocardiographic investigations cannot very well be reconciled with these explanations. With patients suffering from auricular fibrillation whole series of E.K.G.'s can be registered which all resemble each other so much that we are obliged to assume that in those circumstances the contraction-wave always moves through the ventricular muscle in the same, or almost the same way. The manner in which the ventricle contracts and relaxes remains unchanged, and, in spite of this, irregular sizes of pulse appear as a typical phenomenon.

These must therefore have some other origin. In view of the measurements described above, the question arises whether the irregularities may not, perhaps, be explained by the direct mechanical connection which may exist between the different height of two pulses which follow one another.

The mechanical consequence of a pulse is a temporary increase of the arterial blood pressure. If the blood pressure has become high as the consequence of a large pulse, and the ventricle muscle is not very powerful, we can understand that the heart cannot completely empty itself at the next systole, and the pulse thus becomes small. If, on the other hand, during one or more small pulses, the blood pressure has been sufficiently reduced to enable the heart muscle to easily overcome it, the heart at the next systole will be able to drive out a larger portion of its contents, perhaps even all the blood that is in it, and thus again cause a large pulse.

In our curves the variations in the height of the blood pressure, which are of somewhat longer duration, are difficult to estimate, especially as the sphygmograms are all taken from the carotid artery. The air-cushion that was connected to the registering drum was fixed round the neck of the patient by means of a band. This caused his breathing to produce a rhythmical change in the zero of the registering lever. Other slight movements of the patient, such as talking, coughing, &c., also caused difficulties.

Although, therefore, we cannot prove with sufficient certainty from our curves that the blood pressure exercises an important influence upon the size of the pulse, still, on the ground of the above considerations, we regard it as very probable. The variations in the blood pressure in a weakly working heart must be a main cause of the irregularity in the size of the pulse.

The views explained above have reference to the irregular pulse of patients with auricular fibrillation. They can, however, be applied equally well to other abnormalities of the pulse. We refer here particularly to the pulsus alternans.

A number of patients with pulsus alternans have already been examined electrocardiographically, and electrocardiograms have also been published of animals in which a pulsus alternans had been artificially produced. We may refer to a patient formerly examined in the Leyden laboratory,[2] and to the publications of Aug. Hoffmann,[3] Lewis[5] and Kahn und Starkenstein.[4] In so far as the length of the systole can be deduced from the duration of the ventricle electrogram, the curves show that in whole series of alternating pulses the duration of the systole remains constant.*

The theory that alternations of the pulse are to be explained by variations in the duration of the systole can therefore hardly be maintained any longer.

On the other hand, we think that the pulsus alternans may be sufficiently explained by the alternations of the blood pressure, which are produced by the pulse itself in any individual whose blood pressure is relatively high and whose heart is weakened.

BIBLIOGRAPHY.

[1] CUSHNY AND EDMUNDS. "Studies in Pathology," edited by William Bulloch. Aberdeen, 1906, p. 97.

[2] EINTHOVEN. Gesell deutsch. Naturforscher u. Artzte, Verhandl., 1911, 83 Versamml. Karlsruhe, Teil I, p. 80. Sonderabdruck 26, 30; Archives Néerlandaises, Series 11, xi, 239-272.

[3] AUG. HOFFMANN. "Funktionelle Diagnostik und Therapie der Erkrankungen des Herzens und der Gefässe," Wiesbaden, 1911, 189.

[4] KAHN UND STARKENSTEIN. Archiv. f. d. ges. Physiol., 1910, CXXXIII, 579.

[5] LEWIS. "The Mechanism of the Heart Beat," London, 1911, 247, 196, 274.

[6] SAHLI. "Lehrb. d. klinischen Untersuchungsmethoden," Leipzig u. Vienna, 1905, IV. Aufl., 334.

[7] THEOPOLD. Deutsch. Archiv. f. klin. Med., 1907, XC, 79.

[8] WENCKEBACH. "Die Arhythmie als Ausdruck bestimmter Funktionsstörungen des Herzens," Leipzig, 1903, 184.

* We leave entirely out of consideration here the pulsus pseudo-alternans or bigeminus in which the form of *E. K.G.* also alternates.

FURTHER GRAPHIC RESEARCHES ON THE ACOUSTIC PHENOMENA OF THE HEART IN NORMAL AND PATHOLOGICAL CONDITIONS.

By P. J. T. A. BATTAERD.

(*From the Physiological Laboratory, University of Leyden.*)

CONTENTS.

	PAGE.
INTRODUCTION	121
METHOD	123
THE NORMAL HEART SOUNDS	128
The three parts of the first sound	128
Frequency of the vibrations	131
Variations in the character of the sounds	133
Time relations of the heart sounds	137
EXTRASYSTOLES AND ATYPICAL VENTRICULAR CONTRACTIONS	140
Extrasystoles	140
Atypical ventricular contractions	141
SYSTOLIC MURMURS	147
ACCENTUATED SECOND SOUND AND DIASTOLIC MURMURS	149
Accentuated second sound	149
Diastolic murmurs	150
CARDIOPHONOGRAPHY IN AURICULAR FIBRILLATION	153
THE SIMULTANEOUS REGISTRATION OF TWO CARDIOPHONOGRAMS	156
CONCLUSIONS	159
BIBLIOGRAPHY	162

Introduction.

ALTHOUGH methods of objectively recording the sounds of the human heart have existed for a considerable number of years, still this method of investigation has not till a short time ago borne much fruit either for medical practice or for the study of the action of the heart in general.

Earlier researches, such as that by Hürthle,[8] were only directed to the registration of the moment at which the sound sets in.

The first graphic representations of the heart sounds date from nearly twenty years ago.[1] At that time the capillary electrometer was used to reproduce the vibrations of potential produced by the sounds of the heart in a suitably arranged microphonic circuit. Later on the capillary electrometer was replaced by the string galvanometer.[2] The latter is better suited

than the capillary electrometer to the reproduction of rapid variations in potential or current and gives in its tracings a more faithful image of the vibrations of which the heart sounds are composed.

Several other methods have been applied for the recording of the heart sounds. We may mention amongst others those of Hürthle,[9] von Holowinski,[7] Otto Frank,[4] Otto Weiss[11] and Gerhartz.[5] In the papers by the last two full descriptions are found of the work of previous investigators, especially Gerhartz gives an almost complete account of the literature on the subject. We can therefore dispense with the task of again composing an historical survey.

At the same time we feel obliged to discuss the question why, even now, after twenty years, so little progress has been made with the practical application of the methods after they were once developed.

The cause must be mainly looked for in the complicated nature of the methods themselves and the high requirements as regards technical skill which they demand from investigators. The application of the capillary electrometer is accompanied by great difficulties. This instrument often fails the observer at the moment when he has to use it. The mercury surface in the capillary will only move with difficulty or refuses altogether ; to use an expression of Burch's, the instrument becomes " sticky."

The substitution of the string galvanometer for the capillary electrometer has considerably facilitated the work. Although the instrument is costly and requires a schooled staff for its manipulation, it is already found in many clinical schools, where it serves the purposes of electrocardiographic investigation. The same instrument might be used for the purposes of cardiophonography ; yet its adoption to this end has not been general.

This must, on the one hand, be explained by the fact that the technique of the registration of heart sounds is somewhat different to that of electrocardiography. It must therefore be separately acquired. On the other hand, it has also to be taken into account that so far the *E.K.G.** has supplied more data with regard to the action of the heart than the cardiophonogram.

One of the difficulties in the interpretation of cardiophonograms lies in the determination of the exact phase of the heart period, in which the sound or the murmur occurs. This difficulty makes itself specially felt when the heart action is irregular and the character of corresponding sounds shows variations. Possibly this is the cause why a more general application of cardiophonography in clinical practice has been materially retarded.

An excellent means of obviating this difficulty is a simultaneous registration of heart sounds and *E.K.G.*. For this purpose one can superpose in one and the same tracing the heart sounds on the *E.K.G.* as was done by Kahn, Fahr, and others. But the object is much better served by taking two separate curves simultaneously on the same photographic plate. This method was for the first time used by Lucien Bull in the Marey Institute

* *E.K.G.* stands for electrocardiogram. *E.G.* stands for electrogram.

in Paris, it was afterwards tried by others, and quite lately has been applied clinically with very great success by Lewis.[10]

In the Leyden Laboratory we had been working with a similar method for a considerable time, but the publication of the research was retarded by various circumstances. We have now obtained a large collection of photograms on which both kinds of tracings have been taken simultaneously. Only a few of them can be reproduced in this paper. They confirm the results obtained by Lewis and widen them in many directions.

Method.

Though the method which we have used to record the heart sounds is the same as that which has been used for many years in the Leyden Laboratory, still it seems desirable to refer here to some of its details, for we find that many experimenters, in making their cardiophonograms, have encountered difficulties which are probably caused by small technical imperfections of the instruments or the connections used by them.

In the first place attention may be drawn to the tension of the string, which must always be as high as possible. Of course, one must not go so far as to run the risk of the string breaking.

The object of tightening the string can be made clear easily. It is not necessary to discuss here in detail the theory of the reproduction of current oscillations in general. It may be worked out on the theoretical principles[3] which have been already published, and it will form the subject of a future separate publication, where it will be confirmed by a number of experiments made in the laboratory; but a few words of explanation may not be out of place here.

The string, when very strongly stretched and completing its oscillation in a short time, will reproduce current oscillations of not too great a frequency in the right proportion to the current strengths. The shorter the string and the higher the tension the more rapid are the current oscillations which can be reproduced.

If the movement of the string is not aperiodic, its own period must be considerably smaller than the period of the current oscillations which are to be registered.

If these precautions are not attended to and the string is only loosely stretched, the current oscillations of a moderate frequency—for instance, such frequencies as are produced in the microphone by the audible heart sounds—will cause small deviations, whereas slow oscillations of equal amplitude will deflect the string strongly. The image of the heart sound becomes thereby deformed, and this is of even more importance because account has to be taken of the peculiarities of the human ear. The ear is most sensitive to vibrations of 1,000 and 1,500 per second, while the sensibility decreases rapidly and regularly for higher as well as for lower sounds.

These circumstances have already been discussed on former occasions,* and mention has been made of the use of a short string which could be stretched so tightly that its natural vibrations could easily be increased to more than 3,000 per second.

In registering normal heart sounds a string of as high a frequency will not be necessary as a rule, but it would probably be of advantage for the registration of certain kinds of hissing murmurs. In the following chapters we shall return to this question.

We will now add a few words about the other parts of the apparatus, particularly about the transformer and the connections of the electric circuit. These are to be seen in Fig. 1.

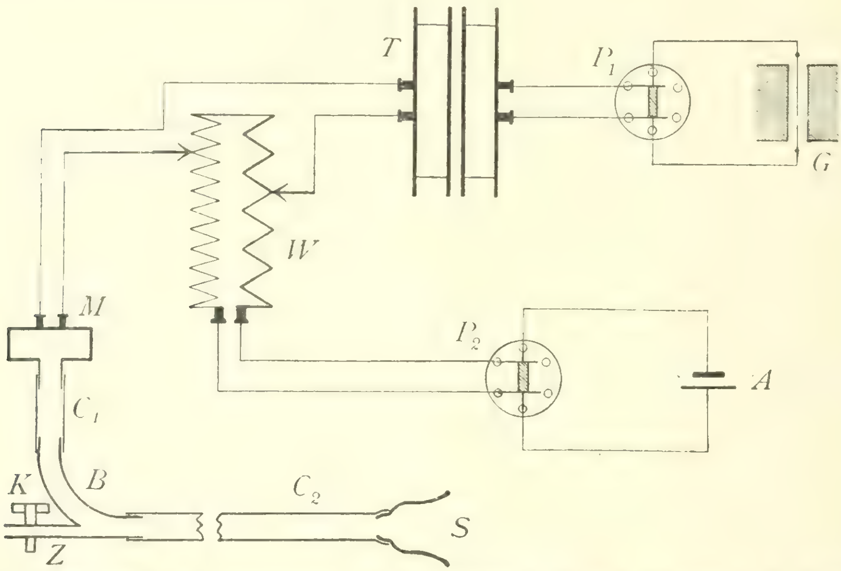


Fig. 1. Diagram of the connections. A, accumulator; P_1 and P_2, keys; W, regulating resistance; M, microphone; S, funnel of stethoscope; T, transformer; G, galvanometer.

The microphone M with its vibration-free Julius suspension, the metal tube B fixed on a pillar with the side-piece Z and the cock K, the thin-walled rubber connecting tubes C_1 and C_2, the latter being about 55 cms. in length, and the stethoscope S were described before.

The primary and secondary coils of the transformer must in all circumstances be placed as close as possible over or against each other. The intensity of the oscillations of the galvanometer might be regulated very easily by moving the secondary coil to or from the primary coil, but this regulation is not necessary, because it can be performed in another manner equally easily and with a special additional advantage to be mentioned further on.

* See the several papers in "Onderzoekingen, Physiol. Laborat. Leyden," 2e Reeks.

The coils of the transformer must not have iron cores, because by hysteresis of the iron the transformation of rapid vibrations would be considerably impeded. The coils must not be taken too small ; those which we use have the shape of round disks, with an opening in the middle, see Fig. 2.

The external diameter D is 24 cms., the internal diameter is 13 cms., the thickness of the disk is 5 cms.

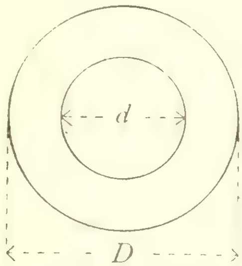


Fig. 2. Transformer. *D*, external diameter ; *d*, internal diameter.

When the dimensions of the disk have been once fixed the thickness of the insulated copper wire, of which the primary coil is wound, is chosen so that the resistance is about the same as the resistance of the microphone. Though in the nature of things the resistance of the microphone is variable, still, a rough average value may be arrived at by means of a few measurements.

Furthermore, if the resistance of the secondary coil is taken as about equal to the resistance of the string, the most advantageous conditions for registering the sounds are obtained.

Next we draw attention specially to the connections of the microphone and the transformer, with the accumulator. By means of a voltage regulator in the form of an adjustable resistance W, the current which is sent through the microphone by an accumulator can be weakened effectively and hereby it is possible to regulate the amplitude of the oscillations of the string at will. Fig. 3 shows an unsuitable manner in which the regulating resistance might be connected up in the circuit ; on the other hand, the proper method is shown in Fig. 1.

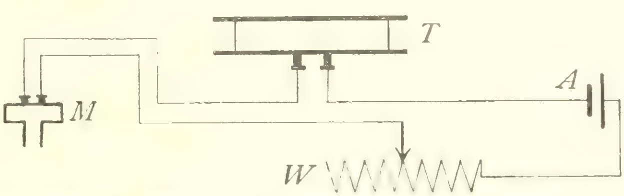


Fig. 3. Disadvantageous connection ; *A*, accumulator ; *W*, resistance ; *T*, transformer *M*, microphone.

If the connection of Fig. 3 is used, an additional resistance not only weakens the current which goes through the microphone, but also increases

the resistance in the microphone circuit. It is owing to the latter circumstance that for a definite current strength in the microphone the current oscillations, which are caused by sounds of a given strength, become less.

If, on the other hand, the connection of Fig. 1 is used, the amplitude of the current oscillations, which are caused by the same sounds, will be determined by the strength of the current in the microphone only. For the resistance W of Fig. 1 is chosen so that that part of it which is in the circuit of the microphone is very small in comparison with the joint resistance of the microphone and the transformer.

The same fact may also be expressed by saying that definite changes of resistance of the microphone form in Fig. 3 a smaller, in Fig. 1 a larger fraction of the total resistance of the microphone circuit.

For the same sensibility of the apparatus a weaker current is therefore used in the microphone with the connection of Fig. 1 than with the connection of Fig. 3, and a weak current has this great advantage, that it is not in itself the cause of variations of resistance in the microphone. It is a well known phenomenon that strong currents have that effect and that this is the reason why the strength of current passing to the microphone circuit should be limited.

In registering heart sounds the use of low voltages, say from 0·2 to 0·5 volt, is as a rule sufficient and in this case the microphone current remains absolutely constant when there are no sounds acting on the microphone.

The electric wires which connect the several instruments must not enclose surfaces through which changing magnetic fields pass, for thereby the steady indications of the galvanometer would be disturbed. We make frequent use of lead cables with two wires or, where this is not possible, we twist together corresponding wires as much as possible. As, however, this is not possible over the complete length of the wires, care must also be taken that they are not moved during the registration, because otherwise they would cut a changing number of lines of force of the earth field.

It is impossible to protect the transformer in the same manner as the conducting wires against the penetration of changing fields of force. The transformer must therefore be kept at a distance from lamps, motors and other apparatus which are fed with alternating currents.

Though it may be perhaps superfluous to mention it specially, we will point out the danger of damaging the string, if the regulating resistance W or the key P_2 (Fig. 1) are handled, before putting the galvanometer out of circuit. It must be a fixed rule that when the galvanometer is in circuit nobody may touch the key P_2 nor the resistance W.

The stethoscope funnel S (Fig. 1) is fixed with strips of leucoplast to that part of the precordium from which the sounds are to be recorded. The strips of leucoplast must be used broad and in sufficient number to make the attachment of the stethoscope to the thorax as completely airtight as possible. If there is an open channel under the leucoplast, causing a communication of the stethoscope with the air, the sounds are transmitted

to the microphone with very much weakened intensity. This phenomenon deserves special attention, because an opening elsewhere in the conducting tubes, particularly at the tap K, does not have the same harmful influence upon the experiments. On the contrary, it is advisable to keep the tap K as wide open as possible, a rule which has been regularly attended to in our experiments.

Generally three stethoscope funnels were fixed on the thorax wall of the experimental subject, one at the place of the *ictus cordis*, where the apex sounds are heard the best, the next on the second intercostal space on the left side and the third in the second intercostal space on the right side beside the sternum. The rubber tube C_2 was then connected successively with each of the funnels, which could be done easily and quickly while the patient or experimental subject remained undisturbed in the same attitude. He was sitting in a chair, with the upper part of the body reclining a little backward.

The respiratory sounds were often disturbing in the registration of the heart sounds. This is not so much the case for the apex sounds as for the aortic and pulmonary sounds. A request to the patient to retain his breath for some time had as a rule no good results, because he was then easily inclined to strain various muscles and so mix muscle sounds with the heart sounds. The best results were obtained by asking the patient to breathe deep and often just before taking the photogram. The apnœa thus produced stopped the disturbing respiratory sounds entirely or for the greater part during the recording.

To avoid further by-sounds the upper part of the body of the experimental subject was uncovered, while the room wherein he sat was heated far above the common room temperature. This was done to prevent shivering. These shivers were sometimes so weak that the observer could not see them, while the patient did not know he was shivering. When asked about it, he would answer that he was not shivering at all, while his shivers and tremblings were clearly shown in the photographic records. As an example of a curve, which was taken in the cold, we refer to Fig. 4.

If the above precautions are taken the heart sounds can be registered almost pure, without taking any particular steps to isolate the room where the patient is from outside sounds. Of course, while the photograms are being taken the banging of doors or stamping on the floor or the staircase must be avoided, but a sound-free chamber specially constructed for the purpose is not necessary, as is proved by the vast number of curves taken by us. These were all taken in the middle of the day in a room near the street and on the ground floor.

While the sounds were registered with one galvanometer, the *E.K.G.* was taken with a second one of the same model. Sometimes, also, we have taken the apex sounds with the one galvanometer and at the same time the aortic or the pulmonary sounds with the other.

For the advantages and disadvantages of a method of this kind we refer to "The simultaneous registration of two cardiophonograms" (p. 156), where also a curve is reproduced.

On the simultaneous use of two galvanometers a detailed publication will appear later on. We will only mention here that the two instruments were placed one behind the other. The image of the first string was projected by a set of microscopes into the field of the second string. Another microscope projected the images of both strings on to the slit before the sensitive plate. Working in this manner only one arc lamp and one time-recorder had to be used.

The normal heart sounds.

The three parts of the first sound. In view of the different descriptions which are given of the normal heart sounds, it seems desirable to mention in some detail the results obtained in our researches.

The first apex sound requires a separate discussion. In it we distinguish three parts, viz., (1) the initial vibrations, (2) the main vibrations, (3) the end vibrations.

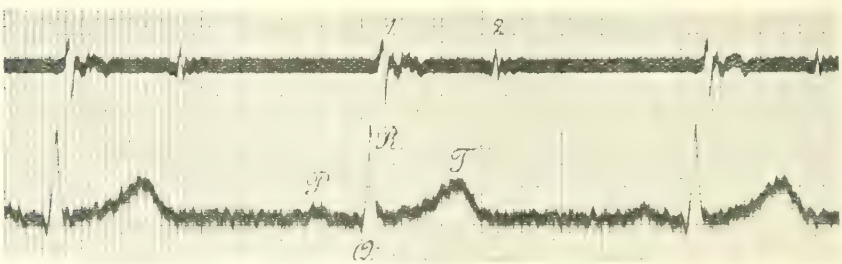


Fig. 4. *Bij.* Apex sounds and *E. K.G.* by lead *I.* Absc. 1 division of the scale = 0·02 sec..

Not every first apex sound shows these three subdivisions equally clearly, but as a rule they can be distinguished, and we venture to reproduce some examples in the accompanying figures.

In Fig. 4 we see the apex sounds and the *E. K.G.* by lead *I* of subject *Bij.* The *E. K.G.* which shows the usual tops *P*, *Q*, *R* and *T*,* is shaky, but the cardiophonogram is very steady in the pauses, so that the beginning of the initial vibrations will be seen to be sharply defined.

The vibrations of the *E. K.G.* must be ascribed to weak shivers of the subject during the taking of the record. The curve dates from a time at which the temperature of the room had not been arranged sufficiently high to prevent these involuntary contractions of the muscles completely. Fig. 4 is especially intended to reproduce the heart sounds and is not rendered

* In all the *E. K.G.* reproduced in this paper one division of the ordinates represents 10^{-4} volt.

less interesting by the vibrations which occur in the *E.K.G.*. On the contrary, it can serve to demonstrate the remarkable fact that weak shivers of the subject, which are insufficient to move the string of the cardiophonogram, may yet render restless the string of the *E.K.G.*.

That the rapid wavelets in the *E.K.G.* of Fig. 4 are really caused by shivers of the subject could be easily demonstrated. For if the chamber temperature was sufficiently raised, the above mentioned waves disappeared from the curve and it became just as steady as the *E.K.G.* of most other subjects.

In Fig. 5 are reproduced the apex sounds and the *E.K.G.* by lead *II* of *Le*.

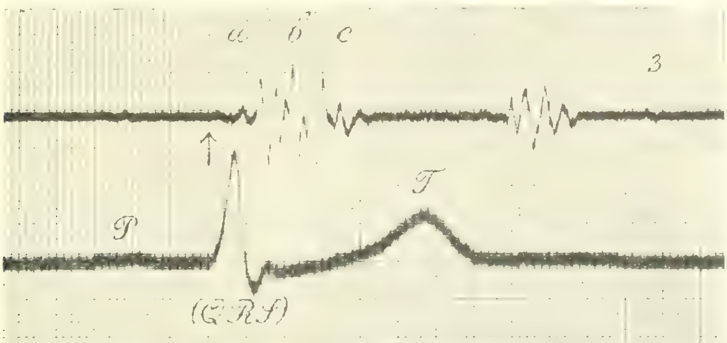


Fig. 5. *Le*. Apex sounds and *E.K.G.* by lead *II*. Absc. 1 division of the scale = 0·01 sec..

The *E.K.G.* shows the tops *P*, *R*, *S* and *T* with this particularity, that top *P* is extraordinarily low. The subject *Le* is remarkable by the great variability in the height shown by his auricular top *P*. On the same day on which Fig. 5 was registered other *P* tops were registered from him of a height of 2·5 mm., *i.e.*, $2{\cdot}5 \times 10^{-4}$ volt by the same lead, thus about six times higher than the *P* top of the above curve.

The three parts of the first sound are marked in the figure with *a*, *b* and *c*. In the cardiophonogram, besides the second sound, we notice a very weak third sound. With this subject the third heart sound was in a number of other curves much more distinct than in the one here reproduced. A further remarkable feature is the presence of sound vibrations which correspond to the auricular contraction. Although they are very weak and would probably be lost to the observer in auscultation, they are undeniably present and that the oscillations of the string in this plate are not accidental but are really connected with the action of the heart, can be inferred from the fact that they appear almost constantly. The number of our diagrams would become too large if we were to furnish a convincing proof by the reproduction of many additional curves.

The auricular sound appearing in the above figure cannot be confused with the initial vibrations of the first apex sound. At a time when the

technique of registering heart sounds was still less developed than is the case at present, some experimenters have sometimes wondered whether there might be some connection between the auricular sound and the initial vibrations of the first apex sound. Curves like the above, recording simultaneously the heart sounds and the *E.K.G.*, remove any doubt which might have existed on this point.

In other places of this paper many more examples of apex sounds will be found reproduced. In comparing the several figures with each other it is to be remembered that the rapidity of the movement of the sensitive plate has varied. The value of one division of the abscissæ in Fig. 4 is 0·02 sec., in Fig. 5 it is 0·01 sec..

Moreover, the amplitude of the vibrations of the string has naturally an influence on the general impression which the cardiophonogram makes on the observer. If the sensibility of the apparatus is much lessened by the voltage regulator in Fig. 1, as was the case in Fig. 6, the initial vibrations of the first apex sound of some systoles are so much reduced in size that they can hardly be distinguished. If, on the contrary, a higher voltage is used in

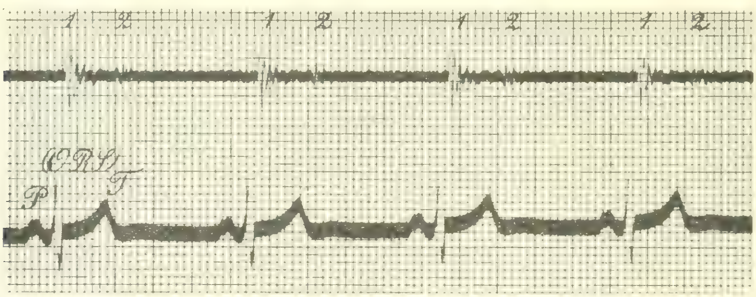


Fig. 6. *d.N.* Apex sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

the microphone the main vibrations of the first apex sound assume such a large amplitude that the string goes out of the field ; but the initial vibrations then show up very distinctly. Fig. 7 is an example of this.

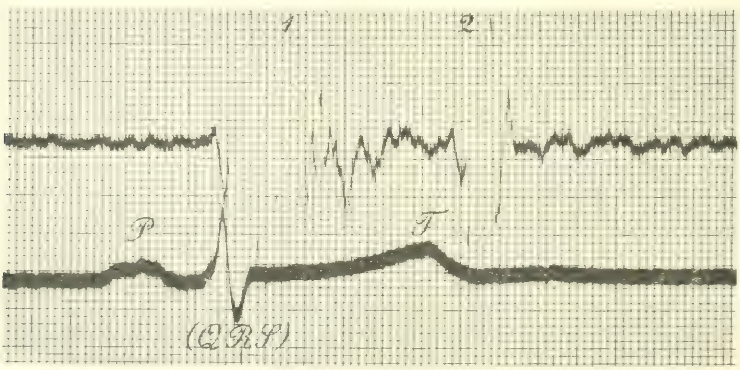


Fig. 7. *d.N.* Apex sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·01 sec..

The last two figures were taken on the same day shortly after each other, from the same subject, *d. N.*. One division of the abscissæ has in Fig. 6 the value of 0·04 sec., in Fig. 7 of 0·01 sec.. In both figures the *E.K.G.* was taken by lead *II*.

Frequency of the vibrations. Several times in the publications from the Leyden Laboratory it has been pointed out that in the cardiophonogram the pitch of the heart sounds cannot be established, because the sounds, as they are recorded, are irregular and can be compared much better with short murmurs than with musical sounds.

This point of view has not been generally accepted. In his detailed study on heart sounds H. Gerhartz[6] has counted the vibrations occurring in a great number of systoles of six series of cardiophonograms, which had been registered in the Leyden Laboratory. He obtains the result that for the one group of apex sounds the average number of vibrations is 39·4 per second. For the other groups of the same sounds this number would be 87·7 ; from these he calculates the mean frequency of the vibrations of all first apex sounds published by us to be 55·5 vibrations per second. In this investigation, however, Gerhartz has counted the vibrations of the curves, as reproduced in the printed publications, instead of using direct copies of the original photograms. Generally the photographic records consist of lines, the thickness of which varies very much, while some parts are so thin that they are lost altogether in the reproduction. As an example we show in Fig. 8 a drawing of a small portion of Fig. 1, magnified ten times from "Die Registrierung der menschlichen Herztöne mittels des Saitengalvanometers." This Fig. 1 is one of those used by Gerhartz in his calculations. The drawing was made by projecting the original negative magnified 40 times on a board upon which a sheet of paper was fixed. On this paper a line was then drawn following accurately the lower edge of the image of the string. The drawing, in which the abscissæ are omitted as being unnecessary for our purpose, was afterwards reduced four times photographically. The original negative represents the apex sounds of *Ba*. The first apex sound of the sixth systole of the plate is reproduced in the drawing.

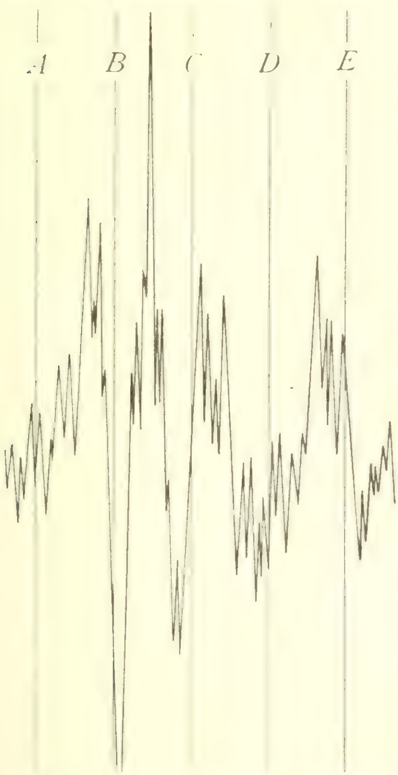


Fig. 8. *Ba.* Copy of a piece of a first apex sound magnified 10 times. Absc. 1 division of the scale = 0·04 sec..

On a close inspection of the drawing, the irregularity of the vibrations is at once sufficiently obvious. For further elucidation we give below in the table the results of a series of measurements about the interval, between the two ordinates B and C. The distance of the ordinates represents a time of 0·04 sec..

TABLE.

Successive reversals.	Distance in thousandths of a second a	Number of complete vibrations per second $\frac{1000}{2a}$
1 — 2	5·1	98
2 — 3	1·3	385
3 — 4	1·7	294
4 — 5	1·9	263
5 — 6	1·9	263
6 — 7	0·6	833
7 — 8	1·8	278
8 — 9	3·1	161
9 — 10	0·5	1000
10 — 11	1·8	278
11 — 12	1·0	500
12 — 13	2·1	238
13 — 14	0·5	1000
14 — 15	3·6	139
15 — 16	2·4	208
16 — 17	1·4	357

The points of reversal of the string movement are numbered in the order from B to C and the numbers are given in the first column of the table. In the second column are the distances between each two successive reversals, expressed in thousandths of a second. The third column gives the pitch of the sounds which would be produced if all succeeding reversals occurred after intervals equal to the last measured interval.

To prevent misunderstanding it should be mentioned that the reversals in the drawing and the times, which are given in the table, do not correspond accurately. The intention with which the drawing is published is only to give an idea of the very complicated nature of a heart sound. Extreme accuracy must not be looked for.

On the other hand, the measurements of the table were made with the necessary care on the original negative, for which the common measuring instruments, which are furnished by Zeiss, have been used.

The irregularity of the vibrations, of which the drawing can give only a general impression, is shown numerically in the table. Sometimes the vibrations follow each other very rapidly, then again more slowly.

It seems to us that no great advantage can be gained by striving to calculate an average frequency of the vibrations from the numbers found. A definite vibration frequency corresponds to a definite pitch, and the

irregularity of the sound is too great for it to be possible to establish the pitch of a normal first apex sound, even approximately. Neither does it appear to us worth while analysing the curve according to Fourier's theorem and thus deducing the vibration frequency of the sine-waves of which they may be considered to consist.

Finally, it may be remarked, with reference to the question of the vibration frequency, that the proper vibrations of the microphone-membrane, and even more those of an only moderately damped string, may be the cause of some sine-vibrations, which are only represented with very small amplitudes in the sound itself becoming specially prominent in the cardiophonogram. This might lead to an important source of error, so that the experimenter, who values the accuracy of his results, will always be obliged to make his string short and to stretch it tightly.

How far he must go in this direction, to get an exact reproduction of the image of the sound, we have already explained in "Method" (p. 1). We do not need to return to that point here.

Variations in the character of the sounds. When a number of cardiophonograms of the same subject are examined one is struck by the fact that the curves often resemble one another so much that the one might be taken for a copy of the other. Indeed, sometimes it is impossible by accurate measurement to show any difference between two corresponding sounds, however apparently whimsical and irregular the shape of their curves may be.

At the same time, as we have remarked before, the shape of the cardiophonogram is not nearly so constant as that of the *E.K.G.*. If the same person is examined at different times, or if the stethoscope is shifted some millimetres on the *regio cordis*, the cardiophonogram often shows an entirely different shape. Perhaps this might be expected. But it is even more striking that often with one and the same subject changes are to be seen in the cardiophonogram for two successive heart contractions which according to their *E.K.G.* do not show any or at least no obvious differences.

This circumstance is illustrated by Fig. 9 and Fig. 10.

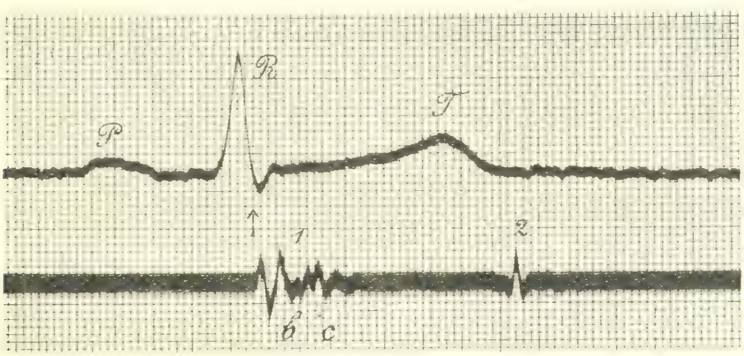


Fig. 9. *Le.* Apex sounds and *E.K.G.* by lead *II*. Absc. 1 division of the scale = 0·01 sec.. There are no initial vibrations.

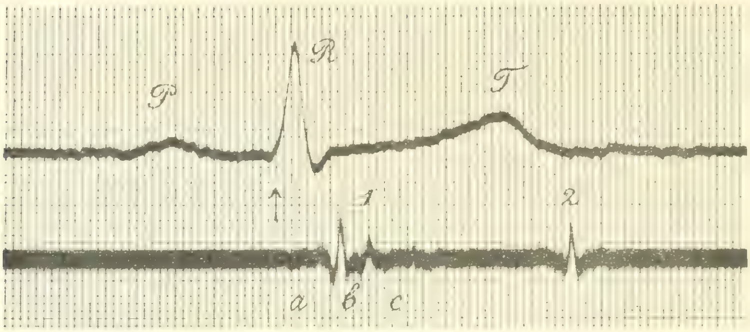


Fig. 10. Another piece of the same photogram of Fig. 9. The initial vibrations are visible and the final vibrations have a different character.

These figures represent two successive heart contractions of the subject *Le*, registered on the same plate. The velocity of the sensitive plate was 100 mm. per second, the *E. K.G.* was taken by lead *II* and the cardiophonograms are of the apex sound. It will be seen that the two successive *E. K.G.* hardly differ at all, but that on the contrary the first apex sound in Fig. 9 shows different phonographic image to that in Fig. 10. In Fig. 9 the initial vibrations are absent, in Fig. 10 they show distinctly at *a*. The main vibrations *b* in Fig. 9 begin with an upward movement of the string, in Fig. 10 with a downward movement, while also the other tops of the main vibrations of both figures differ in form and number. Finally, the after-vibrations *c* in Fig. 10 show a different shape to those in Fig. 9.

Having pointed out these striking differences of the two first sounds, it is remarkable to note that the two corresponding second sounds might almost pass for copies of each other. We regard this circumstance as an accident, however, because the second sounds are generally subject to changes of as great a magnitude as are the first sounds.

An explanation of the variations of the cardiophonograms as above described is easily to be found. A small change in the phase of the respiratory movement may be the cause of more or less lung tissue being interposed between the heart and the thorax wall, by which the transference of the sound, caused by the action of the heart to the stethoscope, is modified. The mutual displacement of the heart and the lungs may quite well be of such a nature that it has no perceptible influence upon the shape of the *E. K.G.*, but can still cause an important change in the character of the heart sounds.

Differences, as described in the apex sounds, also occur in the aortic and pulmonary sounds. Indeed it seems that these are subject to even greater variations. Moreover, it is more difficult to get the arterial sounds clearly than the apex sounds, because they are as a rule much more affected by the admixture of the respiratory sounds.

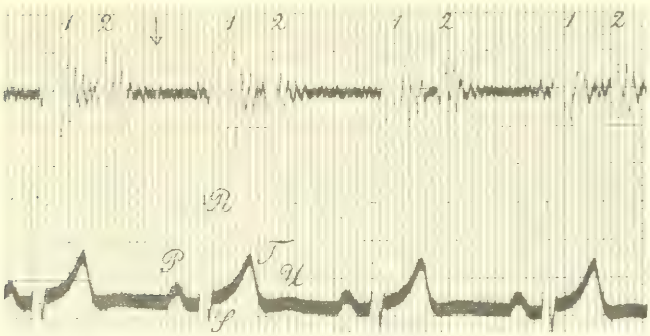


Fig. 11. *Le.* Aortic sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

Fig. 11 gives an example of very variable aortic sounds, in which the time between the first and the second sound is sometimes entirely filled by a clearly visible murmur. On auscultation we could not hear this murmur. The *E.K.G.* represented in the figure is taken by lead *II*, the velocity of the sensitive plate being 25 mm. per second.

In the following, Fig. 12, we give an example of pulmonary sounds, with the *E.K.G.* by lead *II*. The sensitive plate had a velocity of 100 mm. per second.

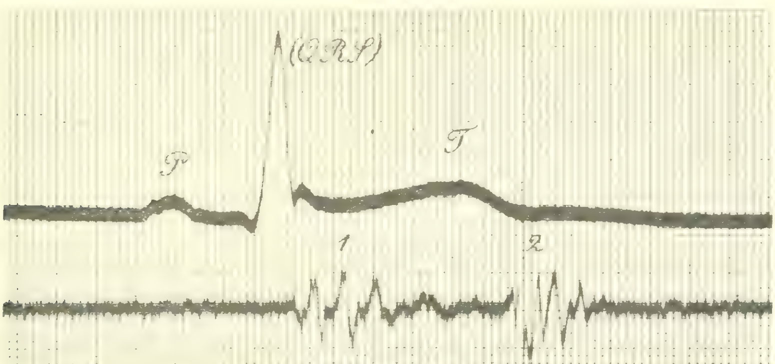


Fig. 12. *B.A.* Pulmonary sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·01 sec..

It will be seen that the string-image, with which the phonogram is registered, is not completely quiet during the heart-pause, though yet sufficiently so to show clearly both sounds.

The vibrations coincide approximately with top *P*, and are perhaps caused by the auricular contraction. But we will not attempt to decide whether or not we are dealing here with a real auricular sound, though a very weak one.

Attention may be rather drawn to the vibrations, which are to be seen between the first and second sounds, and are, just as in the previous figure, as it were a continuation of the first sound. They are relatively much weaker than those in Fig. 11, but still clearly visible, so that by auscultation an audible murmur or at least a drawn out first sound would be expected. Still, both sounds were quite clear in the stethoscope.

Why there can be a difference between the results of the auscultatory and the cardiophonographic examination has already been explained in "Method" (p. 1). We shall return again to this later on in "Conclusions" (p. 159), and therefore leave the subject for the present.

The same phenomenon of clearly visible vibrations between the first and second arterial sounds, in the absence of an auscultatorily audible systolic murmur, is found with a number of our test subjects. It has been already noticed before in *Ba*,* but it must be specially mentioned that the same person who sometimes shows these systolic after-vibrations quite clearly is without them at other times. It seems that these after-vibrations are subject to considerable variations.

We will now say something about the sounds, which we think must be qualified as accidental ones. These are more often seen in the phonograms of the arterial sounds than in those of the apex sounds. The arrow in Fig. 11 indicates an accidental sound of that nature which is visible in the heart-pause shortly after the second aortal sound. We further reproduce in Fig. 13 the pulmonary sounds of *Ba*.

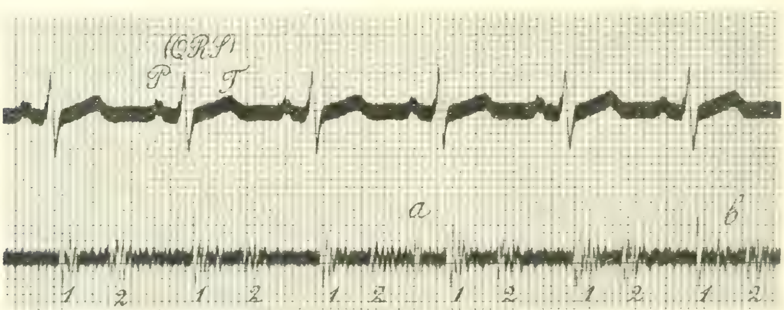


Fig. 13. *Ba*. Pulmonary sounds and *E. K.G.* by lead *I*. Absc. 1 division of the scale = 0·04 sec..

The sensitive plate had a velocity of 25 mm. per second, and the *E. K.G.* is taken by lead *I*. At *a* is to be seen a group of vibrations which in view of the time of their appearance might have been caused by the auricular contraction. The possibility of this being really the case is again not to be excluded, but at the same time we have to point out that in the further curve, and also in a number of other series of curves which we have from the

* Pflüger's Arch. Bd. 117. Taf. 18. Fig. 5.

same person, there are no repetitions of this phenomenon. At *b* a place in the curve is marked where a systolic murmur seems to be present.

We refer later in this paper for the reproduction of another variation, which is often observed in normal heart sounds, viz., a divided second sound.

Time relations of the heart sounds. The investigation of the time relations of the heart sounds has a double interest. If the exact phase of the period of the heart is known, in which a particular sound is produced, the cause of the sound may be better understood and, on the other hand, a comparison of the heart sound with the *E.K.G.* may also throw more light upon the latter curve.

Our original intention to compose a table, in which the results of measurements obtained from a great number of curves would be collected, we have given up. It seems to us that certain important questions which offer themselves are much better to be solved by measurements on some few well selected examples than by calculating averages from many observations several of which, on account of the irregularities which appear in the heart sounds, might give a wrong idea of the real time relations.

We shall begin by comparing the moment at which the first apex sound appears and the time at which the ventricular *E.G.** commences and for this purpose we shall consider the curves of *Le*, the reproductions of which are found in the preceding pages.

As already mentioned, Fig. 9 and 10 show two succeeding heart contractions of the same subject. In Fig. 9 the initial vibrations of the first apex sound are not visible, whereas they are visible in Fig. 10; owing to this the visible sound begins much sooner in Fig. 10 than in Fig. 9. This can be seen in the reproduction with all the necessary distinctness.

For an exact measurement it is desirable to use the original photograms. They show that the first heart sound appears in Fig. 9, 0·065 sec., in Fig. 10, 0·020 sec. after the beginning of the ventricular *E.G.*.

In Fig. 5 are given the apex sounds of the same subject, taken on a different day. The amplitude of the string vibrations in this curve is a little larger than in Fig. 9 and 10 and the initial vibrations show more distinctly. They appear only some thousandths of a second later than the ventricular *E.K.G.*.

In our opinion it would not be of much use for the purpose of obtaining a better insight into the causes of the heart sounds if we were to calculate an average of the values obtained in this manner. The curves show clearly enough that the moment at which the initial vibrations become visible depends on their own intensity and on the sensibility of the registering instruments. Both moments are variable. In establishing the real beginning of the initial vibrations we shall probably come nearest the truth if we make the measurements in circumstances as favourable as possible. This leads us to conclude that the first apex sound appears either at the same time or only some few thousandths of a second after the beginning of the ventricular *E.G.*.

* *E.G.* stands for electrogram, *cf.* note page 122.

The possibility of the electrical phenomena and the heart sounds actually setting in at the same moment cannot be excluded on the ground of our curves, because the time which is needed to transfer the sound from the heart through the stethoscope to the microphone must be taken into account. If the velocity of sound at the temperature of the room is taken at 340 meters per second, the time in question, with our apparatus, in which the sound travels a distance of about 75 cms., becomes 0·0022 sec..

Similar observations made on several other subjects gave corresponding results. Some of them may be mentioned here.

By shows in Fig. 4 the beginning of the initial vibrations of his first apex sound about coincident with the beginning of the ventricular *E.G.*. It has, however, to be taken into account that in Fig. 4 the *E.K.G.* is taken by lead *I*. In most persons the ventricular *E.G.* by lead *II* begins a little earlier than by lead *I*. This is also the case with *By*. A simultaneous registration of the *E.K.G.* by both leads shows that in this subject the difference amounts to about 0·01 sec.; it follows from this that his first apex sound appears about 0·01 sec. after the beginning of the electrical ventricle current.

In *B.A.* we find a time difference of 0·005 sec. when the initial vibrations are present and 0·06 sec. when they are absent. And in *Ba*, also, the measurements give results of the same order of magnitude.

The question arises, how the initial vibrations are to be explained. In the publication "Ueber die Deutung des *E.K.G.*"* the probability was advanced of the initial vibrations being caused by the muscle sound, while the further part of the first apex sound would be composed of muscle sound and valve sound. This opinion is confirmed by the above time measurements.

The curves, which were formerly utilised in the laboratory, were obtained with one galvanometer, by which the heart sounds were superposed upon the *E.K.G.*. The method now used is preferable to the former, from a technical point of view. It gives more exact results in a simpler manner. We also have now at our disposal a much larger number of curves from which the best can be selected. All this explains why formerly a time difference of 0·03 sec. between the beginning of the ventricular *E.G.* and the appearance of the first apex sound was mentioned, whereas at present we accept at the utmost some thousandths of a second in those cases in which the initial vibrations appear at the earliest. And we may feel confident that exactly in those cases in which the initial vibrations are very clear the real proportions are reproduced best.

If the initial vibrations appear 0·03 sec. later they must in the beginning have been too weak to be observed.

The time relations between the electrical phenomena and the sounds of the heart now become evident. The stimulation sends an electrical wave along the heart-muscle; simultaneously, or nearly simultaneously, with a

* Pflüger's Arch. Bd. 149, p. 65, 1912.

difference of only some thousandths of a second, the mechanical process in the muscle begins, by which the muscle sound is produced and about 0·06 sec. later the valves begin to co-operate to produce the first apex sound. The vibrations of the valves, when they begin, form the most important part of the sound.

The first arterial sound begins later than the first apex sound. This fact, already established by earlier researches in the laboratory by means of the capillary electrometer, has been afterwards confirmed by many authors. In these former researches a time difference of 0·061 sec. was established. From the present diagrams we find corresponding values everywhere, where the initial vibrations of the first apex sound are visibly reproduced. For example, in *By* 0·065 sec., in *B.A.* 0·06 sec., in *Le* 0·07 sec..

If the initial vibrations of the first apex sound are not visible, the moments of the beginning of the apex and arterial sounds approach one another. But even then the arterial sounds appear 0·01 to 0·02 sec. later.

The cause of the arterial sound appearing later is obvious. It is mentioned in the previous researches. The anatomical relations make it clear that the heart-muscle sound and the first beginning of the cuspidal sounds can be heard more easily at the apex-cordis than in the second intercostal space. Only when the sound has swollen to a sufficient intensity will it become audible and capable of being registered in the latter place. Thus the time of appearance of the sound must be delayed.

On the subject of the second heart sound we can be briefer than on the first. Its beginning coincides with the last part of the *T*, as already established by former experimenters and, if need be, fully confirmed by the curves published here.

The second sound is produced by the vibrations of the semilunar valves and thus marks the moment at which the systole finishes and the diastole begins. The simultaneous curves of the electrical phenomena and of the sounds of the heart prove the correctness of the view that the systole begins at the commencement of the *Q R S* group in the *E. K.G.* and is finished at the end of *T*.

On the duration of the heart sound we can also be brief. The great variations which are to be observed in the duration of the heart sounds of several persons make it useless to calculate an average for the duration of the first or the second sound. A glance at the many curves seems to us to be much more instructive in this respect than a series of numerical figures would be.

The initial vibrations of the first apex sound, if they appear, have in most cases a duration of about 0·06 sec., the main vibrations last twice as long, 0·12 sec., while the final vibrations are of so variable a character that they may be hardly visible in one person and in another person last almost till the second sound. This last phenomenon is often to be observed in the case of the first arterial sounds.

The duration of the second sound varies between 0·06 and 0·16 sec..

Extrasystoles and atypical ventricular contractions.

Extrasystoles. By extrasystole must be understood any systole which by its early appearance breaks the otherwise regular rhythm of a series of heart contractions. The heart sounds of the extrasystole are connected with its more or less early appearance.

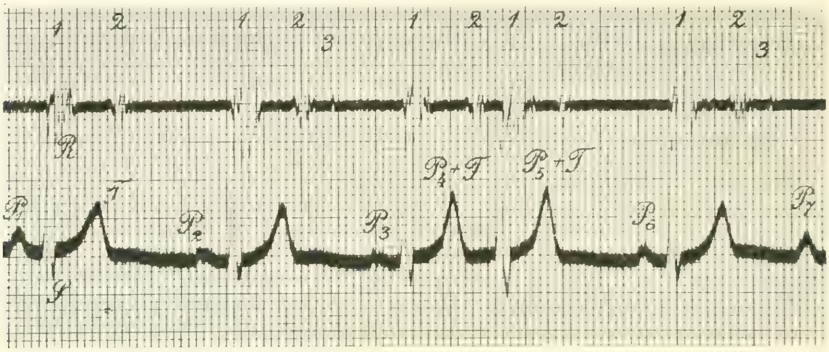


Fig. 14. *Le.* Apex sounds and *E.K.G.* by lead *II.* Extrasystole. Absc. 1 division of the scale = 0·04 sec..

In Fig. 14 we reproduce the curves of *Le*, in which after P_4 an auricular extrasystole appears. In a former chapter we have mentioned that in *Le* the auricular tops show a strong tendencey to vary in magnitude. This property is also clearly visible in Fig. 14. P_1 and P_7 are higher than the other P tops and specially P_3 is very low.

That the extrasystole which comes after P_4 is of an auricular origin is made very probable by the high T of the preceding heart contraction. Comparing the first two *Ts* and the last one on the one hand with the third on the other, it will be seen that the latter is much higher than the three others, by which the supposition is justified that at $P_4 + T$ the auricular top of the following contraction, coincides with the preceding T top. If this idea is correct, and if, therefore, we have really had an auricular contraction preceding the extrasystole, we may ascribe an auricular origin to the latter.

The *E.K.G.* of the extrasystole here reproduced practically does not differ from that of the normal systoles. This circumstance also proves its auricular character. Only its T is seen to appear with an abnormal height, which peculiarity can, however, be easily explained. Probably here, again, an auricular top is blended with a T. In this case the auricular contraction ($P_5 + T$) is, however, not succeeded by a ventricular contraction.

The cardiophonogram shows in two places a distinct third heart sound. It is further to be noticed that the second sound, which is caused by the extrasystole, is weaker and of shorter duration than the second sounds of the other heart contractions. This phenomenon is comprehensible and was

also to be expected. If the systole is premature in its appearance the ventricles cannot be filled completely with blood during the diastole. The quantity of blood which is propelled into the aorta and the pulmonary artery will thus be smaller than normal and in the succeeding diastole the semilunar valves will come together less vigorously than usual. The vibrations of these valves will thus produce a weaker second sound.

If the extrasystole appears earlier, the second sound is weakened still more, disappearing at last, when the extrasystoles appear very early. In our collection of cardiophonograms this phenomenon is more clearly to be seen in the apex sounds than in the aortic and pulmonary sounds.

A few remarks may be added here on the first sound of the same extrasystole. Although this sound is not perceptibly weakened, still it clearly appears later than the other first sounds of the phonogram. The time difference, amounting to 0·7 mm. = 0·028 sec., is probably caused by the absence of the initial vibrations.

The duration of the extrasystole equals the duration of a contraction which appears at the normal time ; this is in the first place proved by the shape of the *E.K.G.* being the same in both cases and confirmed, moreover, by the moment of the appearance of the second sound. In both kinds of systole the second sound begins 7·7 mm. = 0·308 sec. after the summit of *R*.

Atypical ventricular contractions. There are two different circumstances which can cause the development of atypical ventricular contractions. In the first place the passage can be disturbed in a part of the auriculo-ventricular bundle. The stimulation, which comes from the auricle, can only find its way through the remaining part of the bundle and thus reaches only a part of the ventricular wall at the normal time. The other muscle fibres of the ventricle come into contraction some hundredths of a second later.

There are in the main two forms of atypical heart contractions to be distinguished : those of the first kind, in which the conduction takes place only through the left branch ; those of the second kind, in which the conduction takes place through the right branch of the connecting bundle. If the conduction in one of the branches is only partly disturbed, a number of intermediate forms of atypical ventricular contractions occur, according to the localisation of the disturbance.

The second circumstance, by which the development of an atypical ventricular contraction is caused, is the autogenic formation of a stimulus somewhere in the auriculo-ventricular bundle. This heterotope stimulation produces the same forms of atypical ventricular contraction as the above mentioned conduction disturbance ; the same principal forms are also to be distinguished and the development of a number of intermediate forms is again observed.

The next question is : what is the character and what are the time relations of the sounds which are caused by atypical ventricular contractions ?

The answer to this question must be that these sounds in many cases cannot, or can hardly, be distinguished from the normal heart sounds. As a proof we reproduce in Fig. 15 the curves of a subject who has a conduction disturbance in the right auriculo-ventricular bundle. His *E.K.G.* are all atypical and of the first kind. The figure gives the *E. K.G.* by lead *I* above and the apex sounds underneath ; nothing abnormal in the character of the sounds is to be seen.

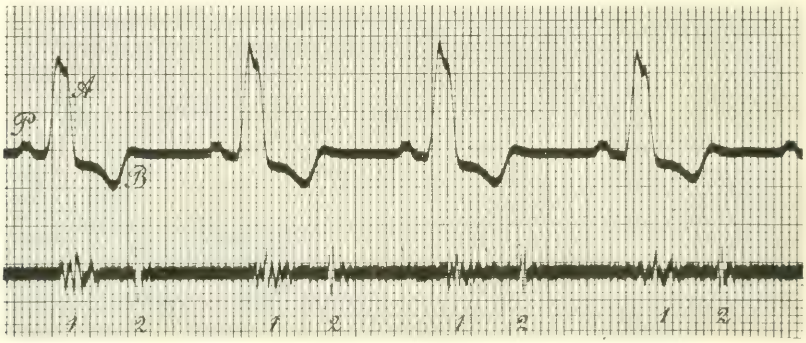


Fig. 15. Apex sounds and *E. K.G.* by lead *I*. Atypical ventricular contractions of the first kind. Absc. 1 division of the scale = 0·04 sec..

With regard to the time relations of the sounds, we may state that the first sound appears about 0·06 to 0·08 sec. after the beginning of the systole. The beginning of the systole itself is always marked out sharply by the beginning of the ventricular *E.G.*, so that the uncertainty of the determination of the time difference is only due to the variability of the first sound and the difficulty of establishing the exact moment at which it begins. The duration of 0·06 to 0·08 sec. agrees approximately with the duration of the initial vibrations in the first apex sound of a normal systole ; for this reason we are inclined to assume that the first sound of an atypical heart contraction agrees with that of a normal typical contraction in regard to the time relations also. We must, however, add that we have never been able to establish distinct initial vibrations in the first apex sound of an atypical ventricular contraction, in so far as our collection of *E. K.G.* and cardiophonograms have been examined on this point. The first sound appears always later—0·06 to 0·09 sec.—than the beginning of the systole.

The second sound of an atypical ventricular contraction appears at about the end of the systole and therefore in its time relations agrees with the second sound of a normal typical contraction. However, it must be stated that the end of a systole is no more accurately observable in an atypical *E. K.G.* than in a *E. K.G.* of a typical form.

An interesting question is the duration of the systole, when it is atypical, as compared with the duration of a common typical ventricular contraction. To measure the duration of a systole we use the *E. K.G.* to fix its beginning

and the cardiophonogram to fix its final point. The time elapsing between the beginning of the ventricular *E.G.* and the beginning of the second heart sound is to be considered as the duration of the systole. This time, which can be measured with all the required accuracy, appears to be different in atypical heart contractions of different origin.

In Fig. 15 the systole lasts 0·44 to 0·48 sec., which time is considerably longer than the normal, which may be placed at 0·31 to 0·35 sec..* The patient of Fig. 15 has a pulse frequency of 59 per minute. Though this frequency is small and the duration of the systole with low heart frequencies is generally somewhat longer than with high frequencies, it seems, that we may speak here of an abnormally long duration, which is not sufficiently accounted for by the few numbers of heart-beats per minute.

It is to be regretted that with this patient all systoles are atypical, so that we cannot make an immediate comparison between typical and atypical heart contractions in the same subject. Fortunately, however, we are able to do that in other cases which we shall discuss at the end of the chapter.

In Fig. 16 are reproduced the *E.K.G.* and the apex sounds of the same patient as in Fig. 15.

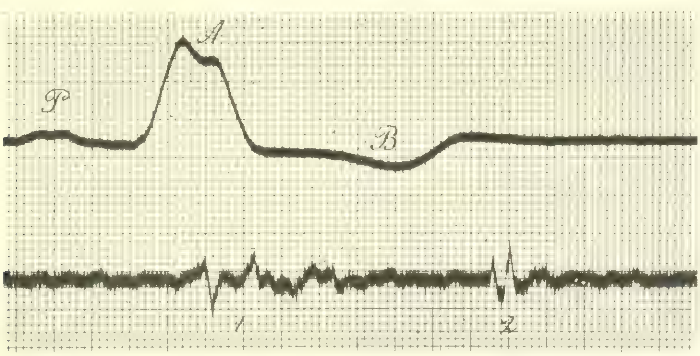


Fig. 16. The same patient as in Fig. 15. Apex sounds and *E.K.G.* by lead *I.* Absc. 1 division of the scale = 0·01 sec..

The atypical *E.K.G.* of both figures are taken by the same lead and are in every way similar to one another; only the speed of the sensitive plate is in the latter four times greater than in the former; the value of one division of the abscissæ of Fig. 16 is 0·01 sec.. In this figure the duration of the atypical systole was found to be 0·475 sec..

The sounds which we have just discussed refer to atypical heart contractions, which are otherwise not distinguished in other properties, for

* See "Onderzoekingen Physiol. Laborat. Leyden." 2e Reeks II, p. 1.

instance, in the time of their appearance, from the common regular heart contractions. The sounds reproduced so far are not characterised by special properties, but it happens very often that atypical systoles appear early, that they are therefore at the same time extrasystoles. In that case the character and the intensity of the sounds can vary in the manner which we have already explained in discussing the auricular extrasystoles. The changes observed in the sounds must then be ascribed not to the atypical

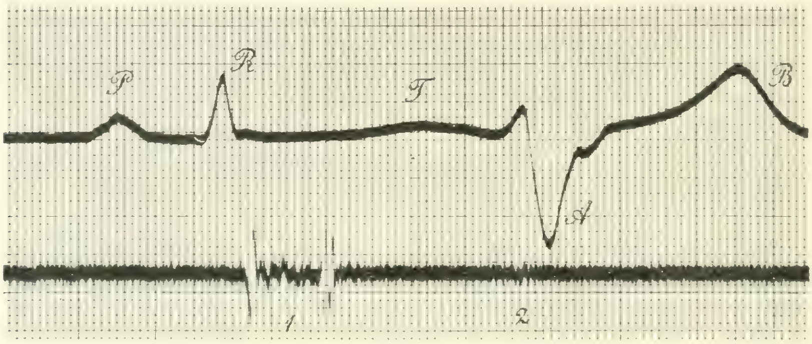


Fig. 17. *Zij.* Apex sounds and *E. K.G.* by lead *II.* Atypical heart contraction as ventricular extrasystole. Absc. 1 division of the scale = 0·01 sec..

nature of the systoles, but to their early appearance. As the stimulus for this kind of systole has its origin in the ventricle, they may be called ventricular extrasystoles.

A beautiful example of the formation of ventricular extrasystoles is given by the patient *Zij.* Fig. 17 gives a reproduction of his *E. K.G.* and his apex sounds. The *E. K.G.* is taken by lead *II* and shows a normal typical contraction followed immediately by an atypical one. The first sound of the ordinary systole is strong and distinctly divided into two parts ; the second sound is only weak. The duration of the systole, measured in the same manner as before described, is 0·37 sec.. The atypical heart contraction, which immediately succeeds the typical one, produces neither a first nor a second sound. This is entirely comprehensible, considering that the new contraction wave is already beginning to move along the ventricle muscle at the moment at which the preceding systole ends. The heart has not had an opportunity to pass into diastole ; no blood has been able to flow into the cavity of the ventricle ; the auriculo-ventricular valves have not been brought into tension by the new contraction wave and the semilunar valves, which were closed after the preceding systole, have simply remained closed.

The image changes altogether when the extrasystole appears less early. In Fig. 18 is reproduced the immediate continuation of the photogram of Fig. 17. In Fig. 18 there is a fairly long pause between the preceding

typical and the subsequent atypical systole and in accordance with this we see that the atypical contraction produces a distinct first sound. The duration of the typical systole is again exactly 0·37 sec., that of the atypical one cannot be measured, as the second sound does not appear clearly enough on the photogram.

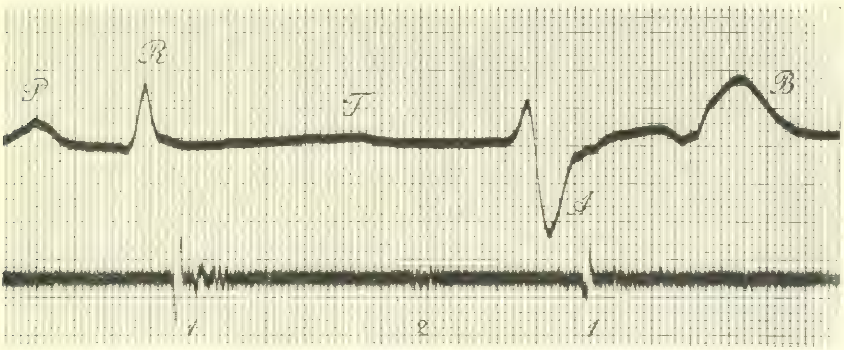


Fig. 18. A following piece of the same photogram of Fig. 17.

We cannot pass from Fig. 17 and 18 without drawing attention to the remarkable phenomenon that the first sound of the typical contraction of Fig. 17 differs so much from Fig. 18. In the latter there is not a trace of doubling or splitting to be seen.

The curves, which are obtained from patient *Zij.*, are very remarkable; they show a great number of atypical heart contractions, which make the rhythm of the heart's action irregular. Fig. 19, 20 and 21 may give an impression of their nature. In all three figures the velocity of the sensitive plate is 25 mm. per second, whereas the *E. K.G.* is taken by lead *II*. In Fig. 19 the aortic sounds are reproduced, in Fig. 20 and 21 the apex sounds. The last two figures are different parts of the same photogram, the last 19 mm. of Fig. 20 being the same as the first 19 mm. of Fig. 21.

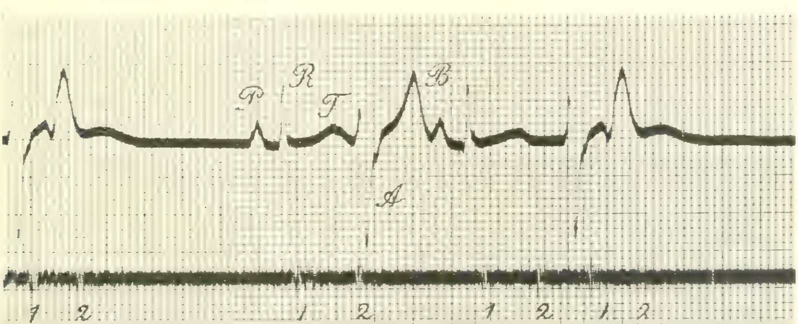


Fig. 19. *Zij.* Aortic sounds and *E. K.G.* by lead *II*. Absc. 1 division of the scale = 0·04 sec..

In Fig. 19 we see the second atypical contraction, appearing very early, without heart sounds; the first atypical one has two apparently normal heart sounds, the last one has, on the contrary, a distinct first sound, but a weak second sound.

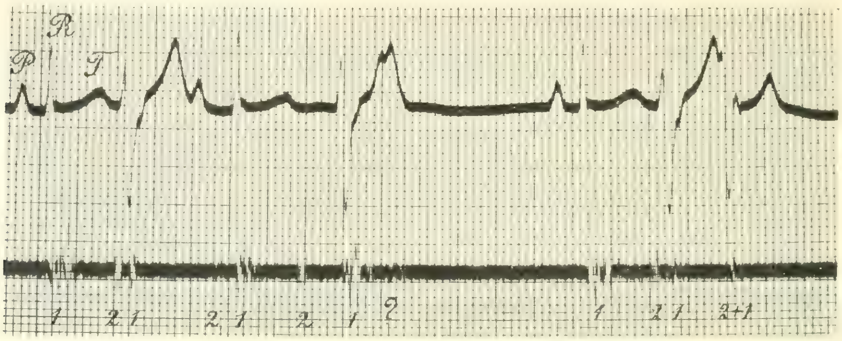


Fig. 20. *Zij.* Apex sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

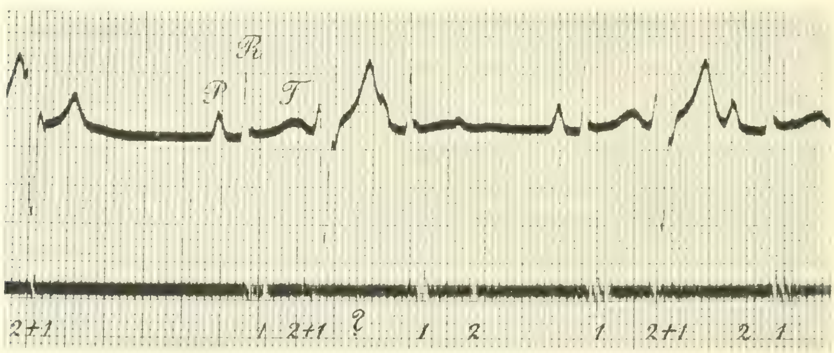


Fig. 21. Another piece of the same photogram as Fig. 20.

The photograms 20 and 21 show similar variations, which need not be further described, as they show clearly enough in the reproductions. Attention may be drawn to the phenomenon that sometimes the first sound of the succeeding systole appears so soon after the second sound of the preceding systole that both sounds together must give the impression of one divided sound or blend completely into one. The places where this is to be seen are indicated in the figure by 2 + 1.

The auscultatory examination of this patient is very confusing. Sometimes three equidistant sounds may be heard, then again sounds in an entirely different rhythm, for which we were not able to give an explanation.

Finally we will say something about the duration of the systoles. In Fig. 19 the systoles, the duration of which is measureable by the *E.K.G.* and

cardiophonogram, have all about the same duration of 0·36 to 0·38 sec.. In Fig. 20 and 21 the typical systoles last about equally long, whereas, on the other hand, some of the atypical systoles occupy much more time. The first atypical contraction of Fig. 20 and the last of Fig. 21 last 0·52 sec..

Systolic murmurs.

Systolic murmurs which are audible show in very various forms in the cardiophonograms. We wish to discuss three of them here. In the first place attention is drawn to a form given in Fig. 22, where the vibrations last with nearly undiminished strength during the larger part of the systole and only become weaker near the end—about the last fifth part of the systole. The weakening is, however, not so pronounced that the murmur

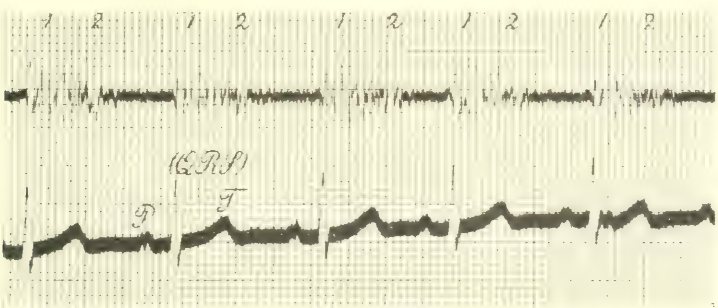


Fig. 22. *B. H.* Apex sounds and *E. K. G.* by lead *II*. Systolic murmur. Abse. 1 division of the scale = 0·04 sec.

comes to an end. On the contrary, it is still clearly present when the second sound sets in, so that the beginning of the second sound cannot be sharply fixed. This is especially the case when the second sound is weak. The systolic murmurs seem to blend with the second sound into one continuous murmur.

Fig. 22 above shows the apex sounds and the *E. K. G.* by lead *II* of an idiotic girl, aged 6. The nature of the vitium cordis could not be properly established. The child was sometimes cyanotic, but neither on percussion nor with the *E. K. G.* could abnormalities be observed. Presumably it was a case of congenital heart disease. In several places of the heart region a strong systolic murmur was audible on auscultation, while also the second sounds seemed now and then to be impure.

A second form of systolic murmur is shown in Fig. 23. The sound vibrations, which are present during the whole systole, are weak in comparison with the vibrations of the second sound, so that the latter appears in the curves with fairly distinct limits.

The beginning of the systolic murmur is formed by vibrations of a moderate amplitude, which do not differ much from the vibrations of a

common first sound. Then weaker and stronger vibrations follow alternately till the murmur ends where the second sound appears.

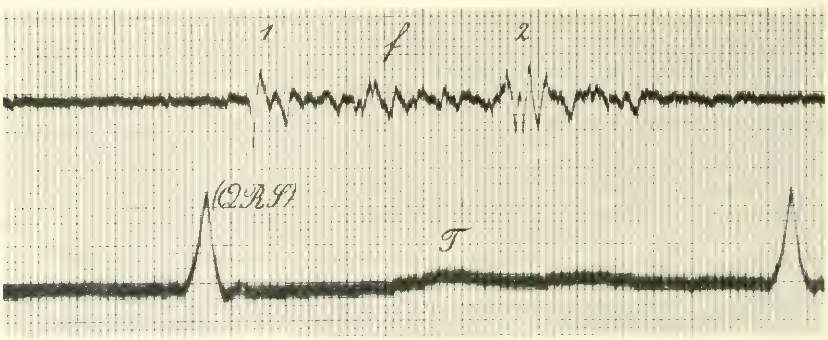


Fig. 23. *M.v.d.L.* Pulmonary sounds and *E.K.G.* by lead *II.* Systolic murmur. Absc. 1 division of the scale = 0·01 sec..

In the patient of Fig. 23 a systolic murmur was audible on auscultation, caused by mitral incompetence. In the cardiophonogram the audible murmur is easily distinguished from the systolic vibrations of first sounds, which are normal on auscultation. For confirmation Fig. 23 may be compared with Fig. 7, 11, 12, and 13. In the latter figures the vibrations in question remain fairly weak in comparison with those of the first sound, and temporary intensifications, like the one marked with *f* in Fig. 23, do not occur.

A third form of systolic murmur is reproduced in Fig. 24, which is taken from a patient with mitral incompetence. On auscultation the systolic murmur was very well audible at the apex of the heart, and it was therefore somewhat surprising to find in the cardiophonogram a fairly well marked pause between the first and second sounds. On a superficial examination the presence of this pause might be the cause of the murmur being overlooked.

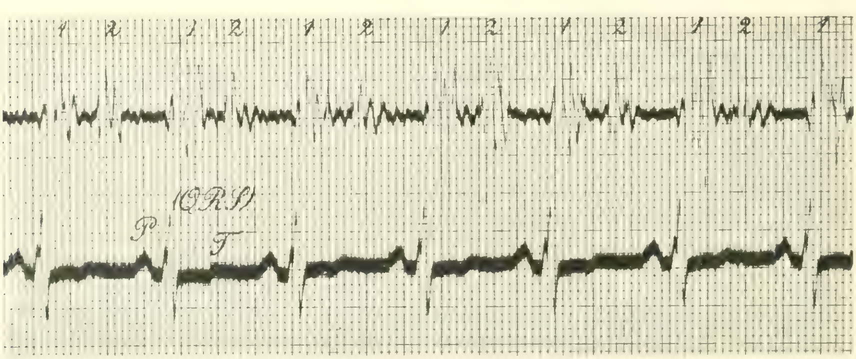


Fig. 24. *Wa.* Apex sounds and *E.K.G.* by lead *II.* Systolic murmur. Absc. 1 division of the scale = 0·04 sec..

But a comparison of the vibrations in Fig. 24 with those of normal first sounds, as reproduced in a previous section of this paper (p. 128), shows very clearly that our patient has a first sound quite different from the normal. The vibrations increase in amplitude during the greater part of the sound and in some heart contractions do not reach their maximum till very shortly before the pause begins. The latter itself is of short duration.

On the other hand, with a normal first sound with visible end-vibrations a wholly different image is produced. A long continued crescendo, as seen in Fig. 24, is never found, while the pause is less pronounced, owing to the longer continuation of the diminished vibration.

Accentuated second sounds and diastolic murmurs.

Accentuated second sounds. In Fig. 25 is an example of a cardiophonogram of an accentuated second sound. The *E.K.G.* is taken by lead *II* and the velocity of the sensitive plate was 25 mm. per sec.. The subject

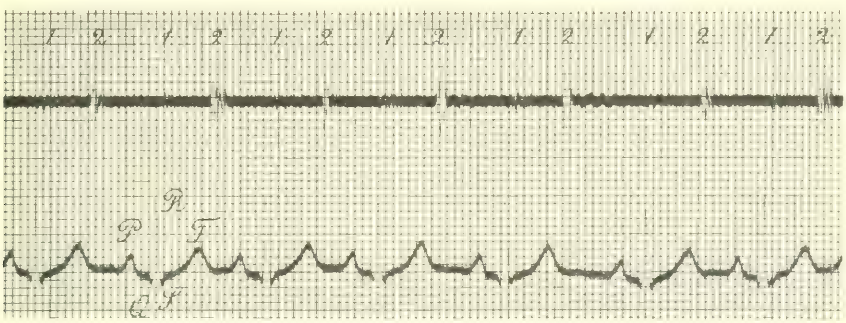


Fig. 25. *J.G.* Pulmonary sounds and *E.K.G.* by lead *II*. Accentuated second sound. Absc. 1 division of the scale = 0·04 sec..

was a boy aged 7, who shows no other deviations in his heart besides the accentuated second pulmonary sound. There are no clinical symptoms which point at a vitium cordis and the *E.K.G.* has the normal form with all three usual leads.

The loudness with which the second pulmonary sound is heard on auscultation is reproduced in the cardiophonogram as it were objectively. The vibrations of the second sound are seen to have a much larger amplitude than those of the first sound. Sometimes the latter are only just visible, whereas the second sound appears everywhere sharply and distinctly. It is, moreover, striking that the character of the second sound is so variable; sometimes the duration of the vibrations is somewhat longer and their amplitude smaller; then, again, they last only for a short time with a large amplitude.

Why in this subject the second pulmonary sound is produced with such great intensity is difficult to explain. On the ground of the above data, it

seems to us that a pathological cause must be excluded. It must be borne in mind that the appreciation of the absolute intensity of the sound, *as it is produced in the pulmonary valves*, is not easy, because external circumstances, as, for instance, the thickness of the thoracic wall, exercise a great influence on the fraction of the vibrations which reach the stethoscope. In auscultation, as well as in the cardiophonogram, we appreciate the loudness of the sound chiefly by comparison, so that in the end we are only able to establish the relative loudness and in the case in question to state that the second sound is much more intense than the first.

Diastolic murmurs. Diastolic murmurs can be easily distinguished according to the moment of their appearing in the diastole.

In Fig. 26 the aortic sounds and the *E.K.G.* by lead *II* are reproduced of a patient who in all probability has a slight aortic incompetence. On auscultation a diastolic murmur was clearly to be heard in the right second

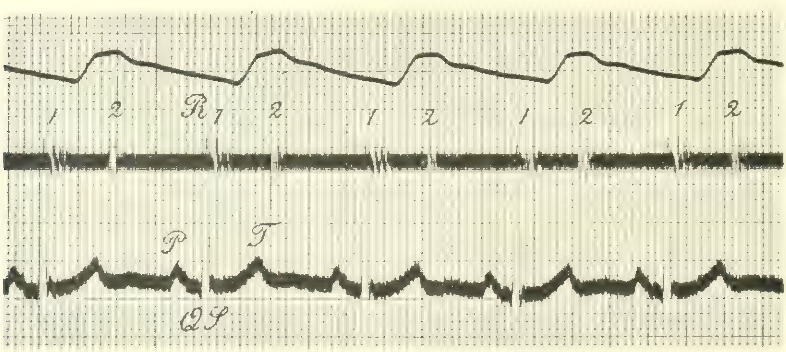


Fig. 26. *K.L.* Aortic sounds and *E.K.G.* by lead *II*. Diastolic murmur blended with the second sound. Absc. 1 division of the scale = 0·04 sec..

intercostal space, but on a first inspection of the cardiophonogram we were disappointed, as the murmur did not seem to show in the curve. However, when the second sound is compared with a normal second sound, it is not difficult to establish a difference.

The character of this second sound is in a sense to be compared with that of the first apex sound of Fig. 24 of the preceding chapter. It is characterised by long continued vibrations of a nearly constant amplitude, and we are forced to assume that the diastolic murmur appears here so early that it is as it were confused with the second sound. The *R* summits of the *E.K.G.* penetrating the curve of the heart sound is a technical fault which does not, however, impair the clearness of the figure.

Curves of a different shape were obtained from another patient with a more pronounced incompetence of the aortic valves. In Fig. 27 are reproduced his apex sounds and *E.K.G.* by lead *II*. We see that the *Q R S*

group is directed downward. With lead *III* this group is even more strongly negative, which is a sign of a hypertrophy of the left ventricle caused by the aortic incompetence.

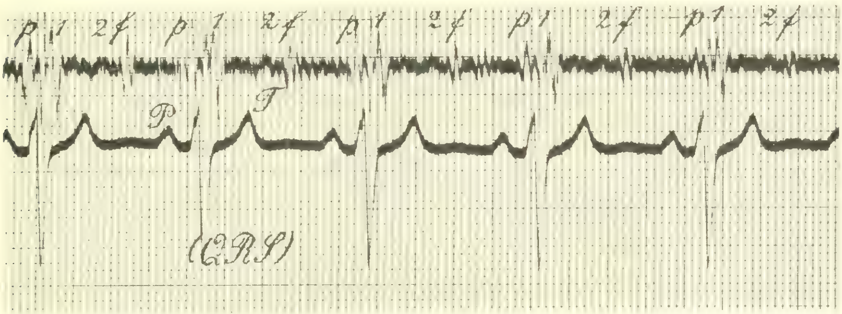


Fig. 27. *d. D.* Apex sounds and *E. K.G.* by lead *II.* Pre-systolic sound and diastolic murmur. Absc. 1 division of the scale = 0·04 sec..

On auscultation, besides a diastolic murmur, a doubling of the first sound was also audible. Of both phenomena, which are clearly shown in the cardiophonogram, the latter deserves separate discussion.

In examining accurately the time relations in the figure it is found that the apparently double first sound is really composed of a pre-systolic sound *p* and the real first sound 1. It is clearly visible that the vibrations which are marked in the figure with *p* appear before the beginning of the ventricular *E. K.G.*, *i.e.*, before the beginning of the systole. They cannot possibly form a part of a systolic sound or systolic murmur. Relying exclusively upon the auscultatory examination, one is necessarily brought to the false conclusion that the whole of the apparently doubled first sound must be of a systolic origin, and the assistance of the registered curves is here required to give the needful explanation.

When once the fact is established that beside the common diastolic murmurs we are dealing with a distinct pre-systolic sound, the further question arises, how this pre-systolic sound is to be explained.

The supposition that the patient in addition to an aortic incompetence is also suffering from a mitral stenosis and that thus the pre-systolic murmur would be of an auricular origin, is not very probable, because the murmur begins to be strong, after the auricle contraction has come to an end, while in a real mitral stenosis—for example in Fig. 29—the pre-systolic murmur appears at the same time as the auricular contraction.

It seems to us that the following explanation is preferable. In an aortic incompetence an abnormally large quantity of blood collects in the left ventricle during the diastole. Indeed the blood flows in from the two sides through the insufficient aortic valves as well as through the mitral valves. Especially after the contraction of the auricle is completed ; and the ventricle

is about to begin a new systole, the latter is so full that its walls may be somewhat stretched, while the mitral valves are almost closing.

Still the flow of the blood through the insufficient aortic valves continues. If by some cause, for example by a stimulation of the vagus, the development of the systole were prevented, the filling of the ventricle would go on, until the pressure in the left ventricle became equal to the pressure in the aorta. But before this condition is reached the ventricle muscle will as a rule begin to contract. The increase of pressure just before the ventricular contraction might set the mitral valves into vibration and thus cause the pre-systolic sound. In this way it becomes comprehensible that in auscultation this pre-systolic sound is confused with the first part of a doubled systolic sound. For both parts of the sound are produced by vibrations of the same valves.

The further diastolic murmurs in the figure depend probably upon the waves of the blood pressure in the aorta and are distributed in a peculiar manner over the diastole, alternately stronger and weaker. The vibrations with the largest amplitude are marked with an *f*. These appear immediately after the second sound, which is itself only weak.

In Fig. 28 we reproduce from the same patient the aortic sounds, taken on a sensitive plate, which was moving with a velocity of 100 mm. per second. The *E.K.G.* is registered by lead *II*. The pre-systolic sound is not visible here, but the common diastolic murmur appears again at the beginning of the diastole and following immediately on the second sound.

When there is a stenosis of the mitral valves the development of the diastolic murmur must be expected, especially at the end of the diastole, that is to say, during the auricular contraction ; we then have the common

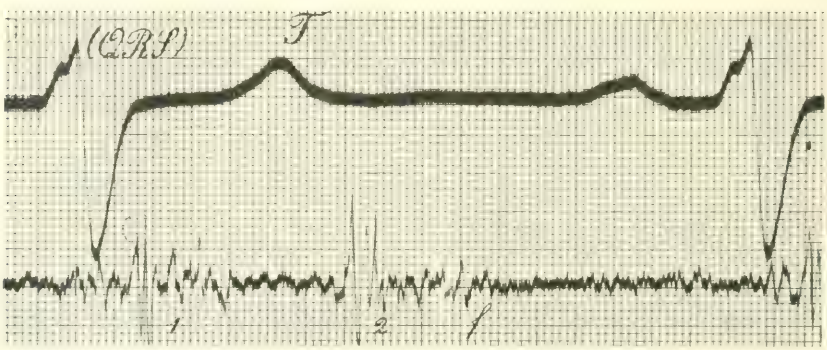


Fig. 28. *d. D.* Aortic sounds and *E.K.G.* by lead *II*. Diastolic murmur. Absc. 1 division of the scale = 0·01 sec..

pre-systolic murmur of which we reproduce Fig. 29 as an example. The sensitive plate had a velocity of 100 mm. per second and the *E.K.G.* is taken by lead *II*. Simultaneously with the auricular contraction, *i.e.*, just before the beginning of the ventricle systole, the diastolic murmur appears at f_I.

With this patient a systolic murmur was also audible. This is to be seen in the curve at f_2.

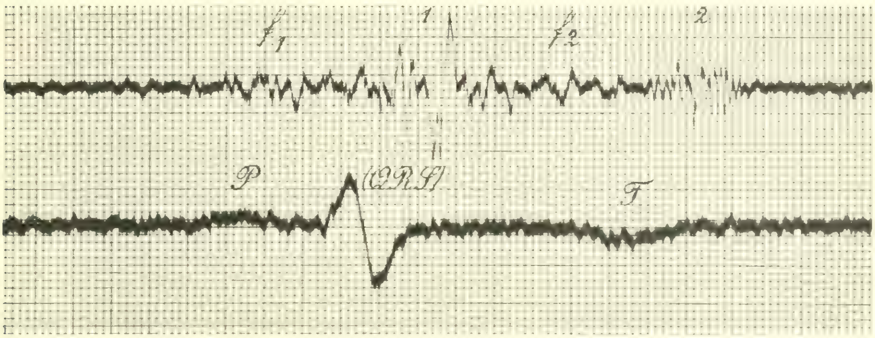


Fig. 29. *d.G.S.* Pulmonary sounds and *E. K.G.* by lead *II.* f_1 diastolic, f_2 systolic murmur. Absc. 1 division of the scale = 0·01 sec..

Cardiophonography in auricular fibrillation.

The disease which is called " auricular fibrillation " was detected for the first time by the use of electrocardiography. Formerly the symptoms which are shown by patients with auricular fibrillation were misunderstood. Owing to the continually irregular pulse these cases used to be included in one group with all other patients with a persisting pulse irregularity. At present the irregularity caused by the extrasystoles can be easily distinguished from that caused by auricular fibrillation, while also the wholly different origin of the so-called sinus irregularity is easily demonstrated.

Patients with auricular fibrillation show so peculiar a picture that it is advisable to discuss their cardiophonograms separately.

In the first place a remarkable feature of this case is the very variable character of their heart sounds, which has already been shown by Lewis. In Fig. 30 are reproduced the aortic sounds and the *E. K.G.* by lead *II* of a patient with auricular fibrillation. The waves in the curve of the *E. K.G.* and the absence of the *P* summit at the place where it always appears in normal circumstances, put the diagnosis of auricular fibrillation beyond all doubt.

In considering the form of the sounds we are struck by the fact that they vary very much. Each of the four first sounds reproduced has a different character : the duration as well as the amplitude and the frequency of the vibrations show each time great variations. Neither are the second sounds equal to one another. Attention may be particularly drawn to the last second sound reproduced which shows a very marked doubling. In auricular fibrillation it is with the sounds as with the pulse, both are *irregularis et inæqualis.*

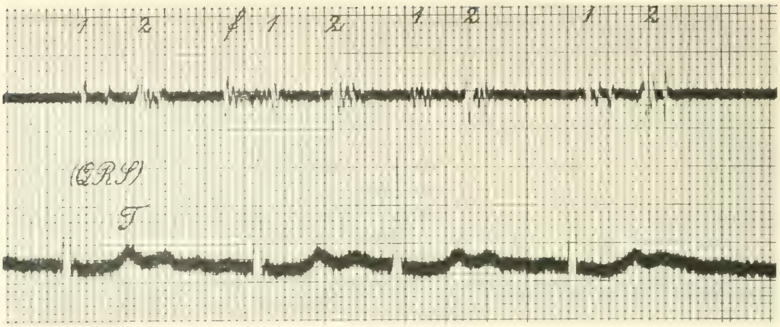


Fig. 30. *v.d.L.* Auricular fibrillation. Aortic sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

Finally we would point out a pre-systolic murmur that is visible now and then in the patient and that is marked with / in the figure.

Another example which demonstrates the great variability of the character of the heart sounds in auricular fibrillation is to be seen in Fig. 31 and 32.

Both reproduce pieces of the same sensitive plate, on which there is only one other systole, situated between the two systoles shown in the figures. Even the first sound of Fig. 31 shows a clear difference from the

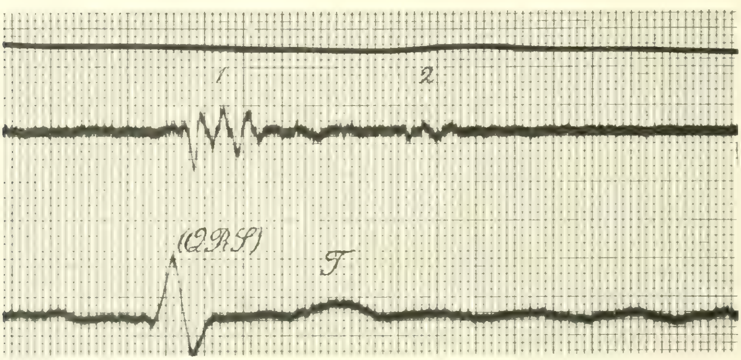


Fig. 31. *v.E.* Auricular fibrillation. Apex sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·01 sec..

first sound of Fig. 32, but the difference of character of the two second sounds is far greater. The amplitude, the duration and the frequency of the vibrations are wholly different and, moreover, the second sound of Fig. 32 is split.

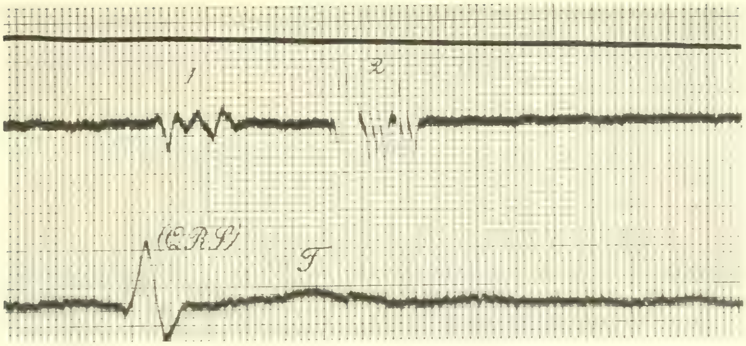


Fig. 32. Another piece of the same photogram as Fig. 31.

Assuming the systole to begin at the commencement of the ventricular *E.K.G.*, the second sound in Fig. 31 appears 0·34 sec. after the beginning of the systole, in Fig. 32, on the contrary, 0·28 sec.. This result may also be expressed by saying that in auricular fibrillation the duration of the systoles is very variable and sometimes amounts to 0·34 sec. and sometimes 0·28 sec., which also contributes to increase the irregularity of the heart action in this disease.

Finally we reproduce in Fig. 33 the apex sounds of the same patient and his *E.K.G.* taken with a velocity of 25 mm. per second. The inequality of the character of the sounds appears very clearly in this figure also, but the

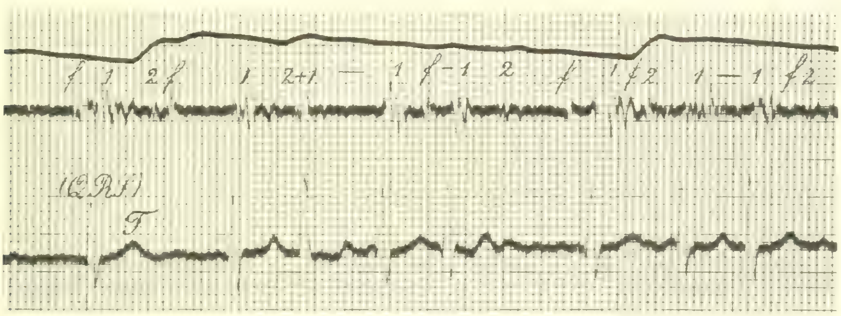


Fig. 33. *v.E.* Auricular fibrillation. Apex sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

object with which we reproduce the figure is not in the first place to demonstrate this phenomenon. We wish to draw attention to the appearance of extra sounds or murmurs, which are marked with *f*; to the irregularity of the moments, at which the sounds are produced; to the absence of a second sound at the places which are marked with a horizontal line; and finally to the blending every now and then of the second sound of a preceding contraction with the first sound of the following contraction.

In Fig. 20 and 21 the cause of irregularity was the appearance of extrasystoles in the form of atypical heart contractions. Here it is chiefly caused by auricular fibrillation. The cause of the irregularity is thus different, but the degree of irregularity is not less. Moreover, in this patient, *v.E.*, the shape of the curve is complicated by an occasional atypical heart contraction. The atypical contraction which appears in the figure and in which the confusing of two sounds is indicated by 2 + 1, is of an intermediate form.

The curve which is drawn above the cardiophonogram shows the brachial pulse taken with a bracelet around the upper arm. The anacrotic elevations in the first of the pulsus should be particularly noticed. The atypical heart contraction and the two following systoles each cause a small, hardly perceptible pulse. Then follows a large pulse, which is caused by the first of the last three systoles, while the last two systoles are accomplished almost without a pulse. The irregularity of the pulse is here just as striking as in the *E. K.G.* and the cardiophonogram.

The simultaneous registration of two cardiophonograms.

As already mentioned, we have in some cases registered with one galvanometer the sounds of a certain point of the regio cordis, while another galvanometer served to register the sounds of another place of the regio cordis.

In Fig. 34 an example is reproduced of a simultaneous registration of aortic and pulmonary sounds. The experimental subject, *Blo*, is a young

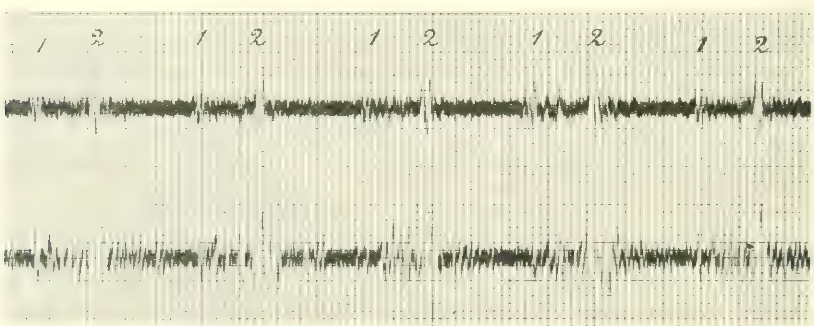


Fig. 34. *Blo.* Systolic murmur. Curve above, aortic sounds; curve below, pulmonary sounds. Absc. 1 division of the scale = 0·04 sec..

man 20 years of age, who, according to the diagnosis, which we think must be made on the ground of ordinary clinical examination, has no organic heart disease. Neither do his *E. K.G.* taken by the three usual leads show any abnormalities.

On auscultation both apex sounds appear to be pure, the second arterial sounds also, but the first arterial sounds are made impure by murmurs.

The first aortic sound is clearly audible, but gives a weak after-murmur. The first pulmonary sound is replaced by a rather weak but long continued murmur. It seems to us that these murmurs have to be reckoned amongst those which are not caused by a defect of the valves.

Even if we disregard the intensity of the sound, the curve of Fig. 34 agrees only partly with the results of auscultation. The curve above shows the aortic sounds. The first and second sounds can clearly be seen, while the murmur, which is also audible between both sounds, is well marked. The pulmonary sounds, which are represented in the curve below, do not, or do hardly, appear separately, in accordance with what might be expected on the ground of the auscultatory examination. The systolic murmur predominates so much here that in most cases the first as well as the second sound seems to be absorbed in it. We draw attention to the clearly visible diastolic murmur that was not audible upon auscultation.

The second sounds of both arteries are considerably stronger than the first sounds. Owing to this the pulmonary sounds give the impression that the sound swells.

At first we had the intention, by a simultaneous registration of two series of sounds, to study in a simple manner their mutual time relations. For instance, the question whether the first apex sound appears before the first arterial sound, and if so by how much, might then be solved by only one photogram, whereas two photograms are needed if a combination of cardio-phonogram and *E. K.G.* is used. But the advantage of a smaller number of photograms is not great. When the instruments are once ready for use it is an easy matter to take a large number of photograms rapidly in succession. By registering first the apex sounds with the *E. K.G.* and then the same *E. K.G.* with the aortic or pulmonary sounds, it is possible to make the measurements much more accurately, because the *E. K.G.* is the most suitable means for an exact time measurement of the phases of a heart period.

If, for the purpose of determining the exact moment at which a sound begins, another sound is made the basis of comparison, there are often difficulties which are caused by the inconstant character of the sounds. For somewhat accurate time measurements a constant basis of comparison is, of course, a main point, and this is given by the *E. K.G.* as by no other curve.

For further confirmation we give in Fig. 35 and 36 a reproduction for the same subject of the aortic sounds and the pulmonary sounds, both with the *E. K.G.* by lead *II*. It will be seen in Fig. 35 that the first aortic sound begins at the same moment as the summit *S*, whereas in Fig. 36 it is not so easy to determine the exact moment of beginning of the first pulmonary sound.

The large vibrations of the pulmonary murmur begin 2 mm., *i.e.*, 0·08 sec. later than the summit *S*; they must therefore also begin later by the same interval than the vibrations of the first aortic sound. The smaller vibrations, with which the pulmonary murmur begins, cannot be or can hardly be

observed, because the string is not quite steady during the heart pause. These movements are caused either by respiration sounds or other sounds which occur in the second intercostal space and make it very difficult to form an opinion of the nature of the systolic pulmonary murmur proper.

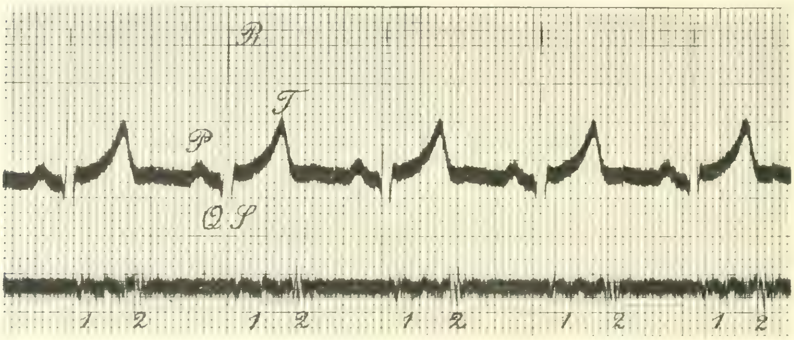


Fig. 35. *Blo.* Aortic sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

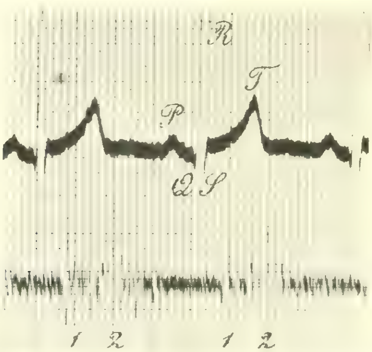


Fig. 36. *Blo.* Pulmonary sounds and *E.K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

Though in Fig. 34 the small vibrations of the pulmonary murmur show better than in Fig. 36, the sound in the former figure, by its great variability and by the restlessness of the string in the heart pause, cannot be very well interpreted. In such circumstances the *E.K.G.* will be all the more appreciated as a fixed basis of comparison.

In order to complete the cardiophonographic image of this subject we reproduce in the following Fig. 37 his apex sounds with the *E.K.G.* by lead *II.* The initial vibrations of the first sound appear shortly after the beginning of *R*, the main vibrations start at the beginning of *S*, while the

after-vibrations, which can be distinguished from the proper sound without much difficulty, lengthen the whole duration of the sound by about 0·07 or 0·08 sec..

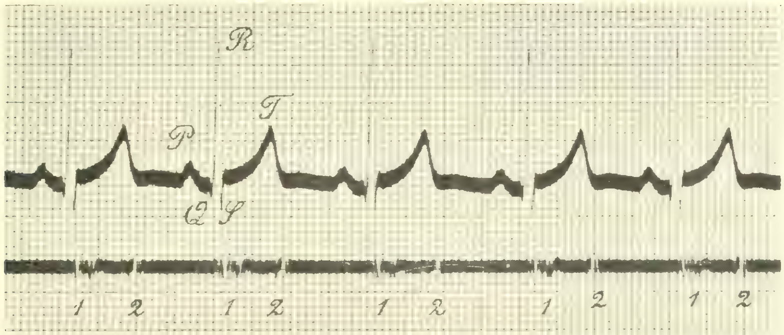


Fig. 37. *Blo.* Apex sounds and *E. K.G.* by lead *II.* Absc. 1 division of the scale = 0·04 sec..

CONCLUSIONS.

Before concluding this paper it will be useful to point out once more the great benefit to be gained from the simultaneous registration of the heart sounds and *E. K.G.* in the analysis of the heart action. The *E. K.G.* we have already called a sure basis of comparison, by which it is possible to fix the several phases of a heart period with greater certainty and exactness than by any other method. This would seem to us to be of special importance for the clinical application of cardiophonography.

If one is dealing with a quite regular heart action, where the sounds are pure and the cardiophonographic curves show sharply defined and practically uniform images for corresponding sounds, the *E. K.G.* is not needed as a basis of comparison. In these circumstances the heart sounds themselves indicate with sufficient exactness the phases of the heart period.

But in other cases, such as occur frequently in clinical practice, the *E. K.G.* cannot well be spared; for instance, when the heart action is irregular, when the character of the heart sounds varies constantly, when the records of the sounds or murmurs are not sharply defined, or when they are made impure by accidental sounds. In all such cases the great importance of a sure standard is obvious.

Speaking generally it may be said that cardiophonography fixes objectively the results which are obtained by auscultation. Even by this alone new light is sometimes thrown upon the acoustic phenomena of the heart. Indeed, the subjective research by itself often leaves the observer in doubt. Very skilled practitioners, who are accustomed to the use of the stethoscope, frequently interpret differently the results of their investigation, while on the other hand their differences can be solved easily and conclusively by cardiophonography.

An important point, which it is impossible to over-emphasise, is the question of the greater or smaller accuracy with which the cardiophonogram is able to give an image of a heart sound or heart murmur. In answering this question two things must be sharply distinguished; on the one hand the objective vibrations, which reach our ear and are the immediate cause of our sound perception, and on the other hand the sound perception itself. The string galvanometer can at its best only render an exact image of the objective vibrations, even when fulfilling ideal demands. An exact image of our sound perception it would probably be very difficult to obtain.

Indeed, the perception which we obtain from one and the same system of objective sounds changes according as we direct our attention more to the one or to the other part of the sound. Just as a listener can follow separately the sounds of any particular musical instrument in an orchestra by concentrating his attention on that instrument, so a particular element of the heart sounds becomes prominent according as attention is fixed upon it. Accidental murmurs do not interfere in that case, when they are not too strong.

The faculty of being able to choose, as it were, what is or is not heard is, for the observer who is auscultating, in some respects a great advantage, which is absent in the cardiophonographic method. The cardiophonogram renders faithfully all the sound vibrations, also those which one would like to efface. The graphic image thereby becomes less characteristic and sometimes difficult to interpret.

In one respect the galvanometer can meet the requirements of the human ear: the tension of the string can be regulated so that the proper period of the string agrees with the vibration period to which the ear is most sensitive. In these circumstances the tone, which sounds the loudest to the ear, will be reproduced also by string vibrations of the largest amplitude. If the tension of the string falls short of this value not only the sound perception but also, as elucidated in "Method" (p. 123), the objectively rapid vibrations will be badly reproduced.

In many places in the preceding pages we have drawn attention on the one hand to easily audible murmurs, which could only with difficulty be made visible cardiophonographically, while, on the other hand, sometimes sounds were regularly and clearly visible in certain phases of the heart period, though they could not be perceived by the ear.

After the above general explanation, it is not necessary to revert to the explanation of this dissimilarity between sound perception and cardiophonogram. We will, however, point out that one must not form an exaggerated idea of this dissimilarity. The numerous figures given above prove sufficiently that as a rule in the main features the similarity may be called satisfactory.

In conclusion we venture to reproduce a striking example of this similarity. In the subject *d. N.* a clearly split second pulmonary sound was heard on auscultation. In Fig. 38 the sound in question will be found cardiophonographically reproduced. The velocity of the sensitive plate is

25 mm. per sec., and the *E.K.G.* is taken by lead *II*. In passing it may be remarked that some small waves, which are seen in the *T* summits of the *E.K.G.* and marked with *x*, have no meaning. They are caused by a technical

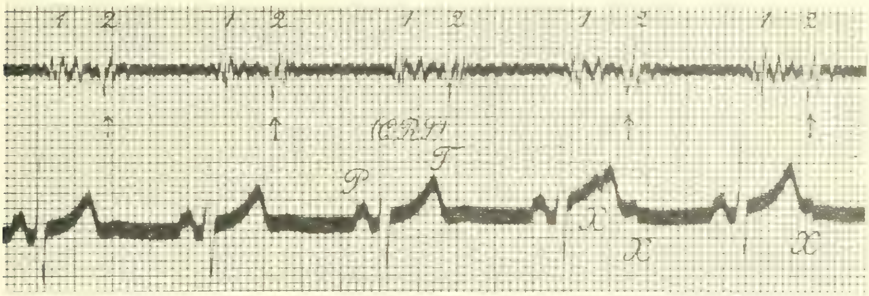


Fig. 38. *d.N.* Pulmonary sounds and *E.K.G.* by lead *II.* Split second sound. Absc. 1 division of the scale = 0·04 sec..

fault; during the registration the compensation apparatus was interfered with, with the result that now and then the compensation was momentarily increased or decreased by 0·1 millivolt. This artificial fault fortunately does not interfere with the object with which the figure is reproduced.

On examining the record minutely it will be seen that the second pulmonary sound consists of two portions, which are separated by a very short pause. The pause in question, which is each time marked in the figure with an arrow, lasts about ¼ mm. = 0·01 sec.. In the third pair of the sounds reproduced the pause is not, or is hardly, present, which proves that in a series of split second pulmonary sounds the splitting is not always equally distinct.

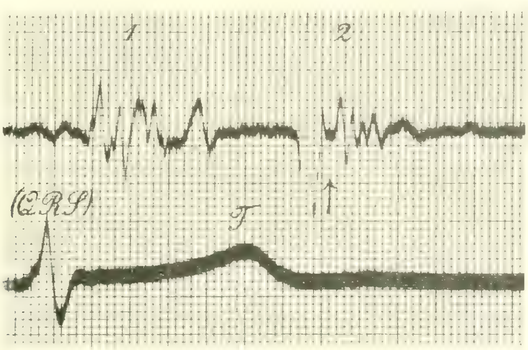


Fig. 39. Absc. 1 division of the scale = 0·01 sec.. The rest as Fig. 38.

No great experience is required to distinguish the pause. A comparison with the other figures, reproduced in this paper, will remove any doubt which might otherwise remain. Attention is drawn to Fig. 17, 21 and 32, which also show split sounds.

In Fig. 39 are reproduced the *E.K.G.* and the pulmonary sounds of the same subject as in Fig. 38, but now with a velocity of the sensitive plate which was four times greater, *i.e.*, 100 mm. per second. The place of the pause in the second pulmonary sound is again marked with an arrow and its duration is here about one division of the scale, or again 0·01 sec..

Perhaps it might be supposed that the ideal of cardiophonography would be reached if it yielded results which without exception agreed with auscultation. We do not consider, however, that such a result must be the aim of the technique of heart sounds registration. It is true that in certain respects the listening ear has an advantage over the galvanometer, in that the former is better able to separate the parts of a compound sound, to which the attention of the observer is directed ; but it must not be forgotten that the same faculty at the same time involves a great disadvantage. While the ear is able to bring some sounds forward, it must naturally be apt to neglect others. The latter does not happen in the galvanometer ; less frequent and inaudible vibrations are also reproduced accurately by this instrument. In this respect cardiophonography gives more than the best investigation by auscultation can ever do.

We need hardly explain that we do not wish to replace the one method by the other in clinical work. As each of the two methods has its own advantages, it is necessary for both to be applied. The results to be obtained in the one way must be completed in the other.

In concluding this paper, we wish to acknowledge to Prof. Einthoven our great gratitude for his kind help and his constant readiness to show us the way in this research.

BIBLIOGRAPHY.

1 EINTHOVEN (W.) AND GELUK (M. A. J.). "Die Registrierung der Herztöne." Archiv. f. d. ges. Physiol., 1894, LVII, 617. Onderzoekingen Physiol. Laborat. Leiden, 2e Reeks II.

2 EINTHOVEN (W.), FLOHIL (A.), AND BATTAERD (P. J. T. A.). "Die Registrierung der menschlichen Herztöne mittels des Saitengalvanometers," Archiv. f. d. ges. Physiol., 1907, CXVII, 461, and Onderzoekingen Physiol. Laborat. Leiden, (2) VII.

3 EINTHOVEN (W.). "Weitere Mitteilungen über das Saitengalvanometer. Analyse der saitengalvanometrischen Kurven. Masse und Spannung des Quarzfadens und Widerstand gegen die Fadenbewegung." Annalen der Physik, IV. Folge, 1906, XXI. See also "Onderzoekingen Physiol. Laborat. Leiden." 2e Reeks VI.

4 FRANK (OTTO). "Die unmittelbare Registrierung der Herztöne." Münchener mediz. Wochenschr., 1904, LI, 953.

5 GERHARTZ (H.). "Die Registrierung des Herzschalles," Berlin, 1911.

6 GERHARTZ (H.). "Herzschallstudien." Archiv. f. d. ges. Physiol., 1910, CXXXI, 530. (*b*) "Die Registrierung des Herzschalles." Berlin, 1911, 64.

7 HOLOWINSKI (A. DE). "Sur la Photographie des bruits du Cœur." Arch. de Physiol. norm. et pathol., 1896, 5me sér. VIII, 893.

8 HÜRTHLE (K.). "Über die Erklärung des Cardiogramms mit Hilfe der Herztonmarkirung und über eine Methode zur mechanischen Registrierung der Töne." Deutsch. med. Wochenschr., 1893, XIX, 77.

9 HÜRTHLE (K.). "Zur unmittelbaren Registrierung der Herztöne." Zentralbl. f. Physiol., 1904, XVIII, 617.

10 LEWIS (TH.). (*a*) "Illustrations of heart sounds." Quart. Journ. of Med., 1912-13, VI, 441. (*b*) "The time relations of the heart sounds and murmurs, with special reference to the acoustic signs in mitral stenosis." Heart, 1912-13, IV, 241.

11 WEISS (OTTO). "Phonokardiogramme." Jena, 1909.

THE EFFECT OF REMOVAL OF LARGE PORTIONS OF THE TOTAL RENAL SUBSTANCE ON THE HEART.*

By F. J. F. BARRINGTON.

(*From the Graham Research Laboratories, University College Hospital Medical School.*)

The following experiments were made to determine whether the mere absence of a large fraction of the total renal substance produced an enlargement of the heart at all comparable to that seen in man in certain forms of renal disease. Cats were used exclusively. The normal range of variation in the size of the heart and kidneys was found by an examination of a hundred individuals of each sex. The hearts were weighed empty of blood and were cut out at the reflexion of the pericardium off the great vessels. The renal vessels were cut as close to the hilus as possible and the true capsules were weighed with the kidneys. Neither castrated males nor pregnant females were included, the former were found to have proportionally much smaller hearts and kidneys than normal males. The following table gives the results ; the weights are in grammes.

	Weight.	Heart.		Both kidneys.	
		Weight.	% of body.	Weight.	% of body.
			Males.		
Maximum	4280	20·33	0·566	62·05	1·748
Minimum	1980	8·17	0·336	16·78	0·628
Mean	3158	13·74	0·435	35·75	1·126
			Females.		
Maximum	3450	17·87	0·712†	46·05‡	1·507‡
Minimum	1835	6·53	0·295	12·17	0·557
Mean	2605	10·52	0·404	22·34	0·858

Ether was the anæsthetic used for all operations. Each experiment consisted in first removing a wedge from the upper pole of one kidney and

* The expenses of this research were defrayed by a Beit Memorial Fellowship and grants from the Graham Research Fund.

† The next lower number in the series was 0·545%.

‡ Both figures came from the same cat which, though in apparent health, had diseased kidneys. The corresponding figures next below were 42·78 gr. and 1·314% which were also from one cat.

subsequently, usually after an interval of three weeks, removing the remaining kidney or tying its ureter.

Fifteen experiments were made of which the following are the summaries.

1. Male. September the 14th, 1911. 2780 gr.. Upper pole of left kidney removed.
September the 28th, 1911. 2495 gr.. Right kidney removed, weight 11·42 gr..
October the 24th, 1911. Dead, appeared well yesterday. Weight 2400 gr. kidney 18·48 gr., heart 0·500 gr.. Kidney somewhat hydronephrotic.

2. Male. October the 30th, 1911. 3200 gr.. Upper pole of left kidney removed, weight 3·03 gr..
November the 21st, 1911. 3490 gr.. Right kidney removed, weight 17·40 gr..
February the 5th, 1913. 3450 gr.. Killed. Heart weighed 17·2 gr. or 0·500% of body weight. Kidney 24 gr. or 0·696% of body. Carotid blood-pressure under ether 160 mm. Hg..

3. Male. October the 30th, 1911. 3425 gr.. Upper pole of left kidney removed, weight 3·29 gr..
November the 21st, 1911. 3650 gr.. Right kidney removed, weight 21·30 gr..
July the 26th, 1912. 2900 gr.. Died with nasal discharge and enteritis. Heart weighed 16·35 gr., kidney 27 gr..

4. Female. December the 1st, 1911. 2325 gr.. Upper pole of left kidney removed, weight 2·00 gr..
December the 22nd, 1911. 2170 gr.. Right kidney removed, weight 9·97 gr..
January the 13th, 1913. 3110 gr.. Killed. Heart weighed 12·8 gr. or 0·412% of body weight. Kidney 15·77 gr. or 0·504%. Carotid blood-pressure under ether 180 mm. Hg..

5. Male. December the 1st, 1911. 3570 gr.. Upper pole of left kidney removed, weight 4·22 gr..
December the 22nd, 1911. 3050 gr.. Right kidney removed, weight 15·56 gr..
June the 4th, 1912. 2800 gr.. Killed. Heart weighed 10·13 gr. or 0·365% of body weight. Kidney 17·35 gr. or 0·619% of body.

6. Female. March the 29th, 1912. Upper pole of left kidney removed, weight 1·95 gr..
April the 19th, 1912. 2160 gr.. Right kidney removed, weight 13·37 gr..
April the 20th, 1913. 1990 gr.. Killed. Heart weighed 7·30 gr. or 0·367% of body weight. Kidney 12·11 gr. or 0·609% of body.

7. Male. January the 22nd, 1913. 2735 gr.. Upper pole of left kidney removed, weight 2·17 gr..
February the 2nd, 1913. 2675 gr.. Right ureter tied.
February the 23rd, 1914. 3900 gr.. Killed. Heart weighed 13·92 gr. or 0·357% of body weight. Kidney (left) 34·55 gr. or 0·809% of body. Carotid blood-pressure under ether 200 mm. Hg.. Right kidney a hydronephrotic sac.

8. Male. September the 22nd, 1913. 3500 gr.. Upper pole of left kidney removed, weight 4·31 gr..
October the 12th, 1913. 3300 gr.. Right ureter tied.
October the 22nd, 1913. 2620 gr.. Killed. Not feeding well some days. Heart weighed 11·65 gr.. Left kidney 12·13 gr.. No hydronephrosis of the right kidney.

9. Female. September the 22nd, 1913. 2325 gr.. Upper pole of left kidney removed, weight 2·67 gr..

October the 12th, 1913. 2500 gr.. Right kidney removed, weight 9·31 gr..

November the 17th, 1913. 1520 gr.. Dead. Not feeding well four weeks. Heart weighed 6·93 gr.. Kidney 7·16 gr..

10. Female. September the 22nd, 1913. 2635 gr.. Upper pole of left kidney removed, weight 2·44 gr..

October the 12th, 1913. 2525 gr.. Right ureter tied.

December the 2nd, 1913. 1750 gr.. Dead. Nasal discharge. Heart weighed 8·34 gr.. Left kidney 12·91 gr.. Right kidney moderately hydronephrotic.

11. Female. September the 30th, 1913. 3175 gr.. Upper pole of left kidney removed, weight 3·96 gr..

October the 21st, 1913. 3120 gr.. Right kidney removed, weight 17·01 gr..

April the 18th, 1914. 3850 gr.. Dead. Full term pregnancy. Weight without pregnant uterus 2725 gr.. Heart weighed 13·49 gr.. Kidney 19·30 gr..

12. Female. September the 30th, 1913. 2950 gr.. Upper pole of left kidney removed, weight 3·50 gr..

October the 21st, 1913. 2700 gr.. Right kidney removed, weight 15·62 gr..

November the 12th, 1913. 1650 gr.. Dead. Heart weighed 8·04 gr.. Kidney 8·27 gr..

13. Female. September the 30th, 1913. 2375 gr.. Upper pole of left kidney removed, weight 2·58 gr..

October the 21st, 1913. 2460 gr.. Right kidney removed, weight 11·37 gr..

November the 22nd, 1913. 1570 gr.. Dead. Heart weighed 6·12 gr.. Kidney 9·43 gr..

14. Female. September the 30th, 1913. 2075 gr.. Upper pole of left kidney removed, weight 2·50 gr..

October the 21st, 1913. 2050 gr.. Right ureter tied.

March the 18th, 1914. 2900 gr.. Dead. Pregnant nearly full term. Weight without pregnant uterus 2350 gr.. Heart weighed 9·86 gr.. Left kidney 13·93 gr.. Right kidney a hydronephrotic sac.

15. Female. December the 4th, 1913. 3480 gr.. Upper pole of left kidney removed, weight 3·64 gr..

December the 31st, 1913. 3510 gr.. Right ureter tied.

February the 8th, 1915. 3180 gr.. Killed. Heart weighed 14·43 gr. or 0·454% of body weight. Left kidney 20·34 gr. or 0·679% of body. Right kidney a hydronephrotic sac.

All the cats were kept in a large cage during a considerable part of each experiment, so that they got a fair amount of exercise.

It will be seen that in five cases (1, 8, 9, 12 and 13) the well-known wasting symptoms produced by the removal of an excessive proportion of the total renal substance developed. In two (3 and 10) the cats died with an accidentally acquired, wasting, infectious disease. It is evident that no conclusions involving the relative size of the heart can be drawn from any of these seven experiments, since in emaciation the heart is known to waste less than the whole body. Two (11 and 14) became pregnant months after

the operation and died at full term : it is not known what symptoms they exhibited but both appeared quite well the day before death. It appears possible that, though the remaining amount of kidney was sufficient to keep them in health in ordinary circumstances, it was insufficient in the later stage of pregnancy. Neither of these cats can be considered for the present purpose, as the normal relative size of the heart in pregnancy was not determined.

There remain six cats (2, 4, 5, 6, 7 and 15), three of either sex, which remained healthy till killed. In these the percentage weight of heart to body was well within the normal limits. The mean in males was 0·407 % and in females 0·411 %, the former being below and the latter above the normal mean.

It may therefore be concluded that the removal of such fractions of the total renal substance as are compatible with prolonged life produces no cardiac hypertrophy in cats.

EFFECTS OF UNILATERAL DEPRESSION OF VENTRICULAR CONDUCTIVITY.

By A. L. PRINCE and L. A. GERACI.

(*From the Laboratory of Physiology, Yale School of Medicine.*)

In 1868 von Leyden[1] described a case of arrhythmia in which he stated that an interval of several tenths of a second elapsed between the beat of the left and right ventricles. Recently cases supporting this observation have been reported by von Leyden and Bassenge,[2] Hewlett[3] and others. To this form of irregularity the terms hemisystole, interventricular dissociation and intraventricular block have been applied.

The validity of this diagnosis has been contested by Riegel,[4] Hering,[5] and Helsingius.[6] These authors are of the opinion that the curves published by von Leyden do not differ materially from those obtained in cases of pulsus bigeminus of extrasystolic origin.

On the basis of our present conception of cardiac conductivity such an arrhythmia is difficult to explain. At first sight one might consider it as the result of an interference with the passage of the impulse from the auricles to one of the ventricles; in other words, a block in one or the other of the two main divisions of the His bundle. This explanation, however, lacks experimental support.

Biggs[7] in experiments on the isolated rabbit's heart was unable to discern any alteration in the interventricular rhythm after complete section of the descending limb of the His bundle supplying one ventricle. This author therefore concludes that, "Probably the left and right branches of the *A-V* bundle are not confined in their distribution to their own side of the heart, but supply both ventricles, for it looks as though auricular impulses were always capable, when one of the two primary branches was divided, of reaching both ventricles simultaneously through, presumably, the other uninjured branch." This conclusion certainly receives no support from the known anatomical distribution of the His bundle in the mammalian heart.

Barker and Hirschfelder[8] in similar experiments on the dog's heart *in situ* come to the more plausible conclusion that "the His bundle plays little if any role in the co-ordination of the two ventricles," furthermore, "The muscular bridge between the two chambers is formed by the entire musculature of the heart wall and hence there is no such narrow connection as is present between atria and ventricles at which a block might be produced." In confirmation of their results these authors quote the observations of Saigo[9] who found areas of fatty degeneration and myocarditis involving the left branch of the His bundle in several cases in which there had been no evidence of ventricular inco-ordination during life.

On the other hand, with the aid of the string galvanometer, Eppinger and Rothberger[10] after section of one of the two main divisions of the His bundle observed a delay of ·02 to ·04 sec. on the side of the heart thus isolated. But even this delay is insufficient to explain the marked asynchronism supposed to occur in clinical hemisystole.

The view that interventricular inco-ordination may arise from the contraction of isolated portions of the ventricles has been advanced by Schmoll.[11] Such a limitation of ventricular activity would necessitate an extensive blockage of impulses in the myocardial tissue of the ventricles, a conception not supported by experimental evidence.

In the experiments here to be reported we investigated unilateral depression of the ventricles as a possible factor in the production of interventricular arrhythmia. Depression was obtained by means of cold applied directly to the interior of the cavity either of the right or left ventricle. From the superficial situation of the main branches of the His bundle and their ramifications, it appears plausible that cold so applied will at least interfere with the normal transmission of impulses in the conducting system on the cooled side.

Method.

Our experiments were performed on the excised heart of the cat. The animals were decapitated and the heart removed after ligation of the pulmonary artery. A cannula was inserted in the aortic stump and perfusion begun. The perfusion fluid consisted of equal parts of defibrinated sheep's blood and Locke solution. The mixture was impregnated with a half volume of CO_2 (at 20° C.) and saturated with oxygen. The perfusion pressure (150 mm. Hg.) and the temperature (37° C.) were maintained constant.

The apparatus (Fig. 1), a modification of that recently described by Henderson and Prince,[12] consisted of two vertical cylindrical chambers (A, A′) 2 cm. in diameter and 20 cm. in length fitted at their inferior extremities with glass cannulæ 6·5 mm. in bore. These cannulæ were inserted into the respective ventricles through a slit in the auricular appendage. The closure of the auriculo-ventricular valves about the cannulæ prevented regurgitation into the auricles. Two tubes (B, B′) extending to the base of the cylinders delivered a constant flow from two reservoirs containing Locke solution, one at 5°, the other at 37° C. Each cylinder was so connected that the intraventricular temperature could be varied at will. As the beating of the ventricles provided for the thorough mixing of the fluid in the cylinders, the thermometers (C, C′) gave the approximate intraventricular temperature. Extending laterally from the cylinders were two water traps (D, D′) which served not only as an outflow for the intraventricular perfusion but also to maintain a constant venous pressure of 50 mm. of saline for the right ventricle and 100 mm. for the left. These water traps consisted of glass tube 2 mm. in diameter, capped with small test tubes and fitted with rubber tubing to regulate the outflow.

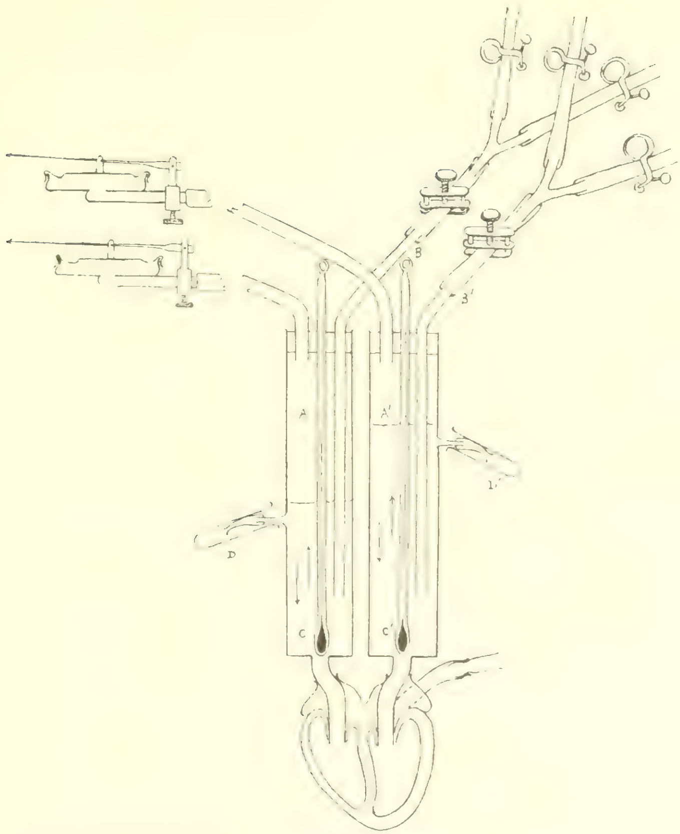


Fig. 1. At each heart beat the oscillations of the fluid in cylinders A, A′ are transmitted to the recording tambours. The intraventricular temperature variations are obtained by means of tubes B, B′ delivering a constant flow from two reservoirs (not shown in figure) containing Locke solution, one at 37°, the other at 5° C.. The venous pressure is regulated by the two water traps D, D′.

As we sought to determine exactly the instant of the beginning of ventricular systole, errors that might arise from changes in the rate of flow from the traps were carefully controlled. Our control experiments show that the changes in pressure within the cylinders were too slight to alter the rate of flow from the traps to any significant extent and furthermore the inertia of the fluid passing through the traps was sufficiently great to prevent errors of transmission, the slightest change in intraventricular volume being transmitted to the recording tambours without measurable delay.

The inception of ventricular systole as well as the character of the volume curve of the right and left ventricles were recorded with very sensitive Marey tambours. A vibrating reed gave the time in ·02 sec.

From the tracings the following determinations were made :—1. The interventricular period (the time elapsing between the beginning of systole of the two ventricles). 2. The time relations of systole and diastole in the normal and cooled sides of the heart. 3. The heart rate.

Results.

Our conclusions are based on seven experiments. In all experiments the following procedure was adopted : After a control period in which the intraventricular temperature in both ventricles was maintained at 37° C., the temperature of one or the other ventricle was gradually lowered and kept at from 6° to 10° C. for various periods of time. The temperature was then restored to normal. In the majority of experiments this procedure was repeated several times and the effects of cooling the left and right ventricles studied individually.

In view of their uniformity a general description of the results will suffice.

Effect on the interventricular rhythm. One of the effects of unilateral cooling is the appearance of a pause between the inception of systole in the normal and the cooled side (Fig. 2, 3, 4, and 5). This interventricular pause is roughly proportional to the degree of cold applied and appears usually at about 15° to 20° C.. In susceptible hearts this delay appears after cooling only to 30°. In only one instance was it found necessary to prolong cooling at 10° C. in order to induce arrhythmia. On restoring the temperature of the cooled ventricle, the interventricular pause disappears at about the same temperature necessary to induce it.

In seeking an explanation of this interventricular pause one must consider at least three factors : the depressing action of cold upon the function of (1) the auriculo-ventricular bundle ; (2) the Purkinje network ; and (3) the ventricular muscle itself. Our method did not permit a separate study of these factors, but from the results of Eppinger and Rothberger[10] it may safely be argued that no delay in excess of ·02 to ·04 sec. can be attributed entirely to depression of conductivity in the auriculo-ventricular bundle. The more prolonged interventricular delays are presumably to be attributed to unilateral cooling of the Purkinje network which is normally the most rapid path of conduction of interventricular impulses. It is, however, conceivable that the Purkinje network, by extreme degrees of cooling, may also be brought to a point of maximal depression. Should this be the case, further prolongation of the interventricular pause would have to be attributed to depressed muscular irritability or conductivity.

Additional evidence of the depressing influence of cold on cardiac irritability was obtained in experiments on the frog's heart. Applying a ligature at the auriculo-ventricular junction, the non-beating ventricle was stimulated with uniform minimal break shocks after exposing the preparation

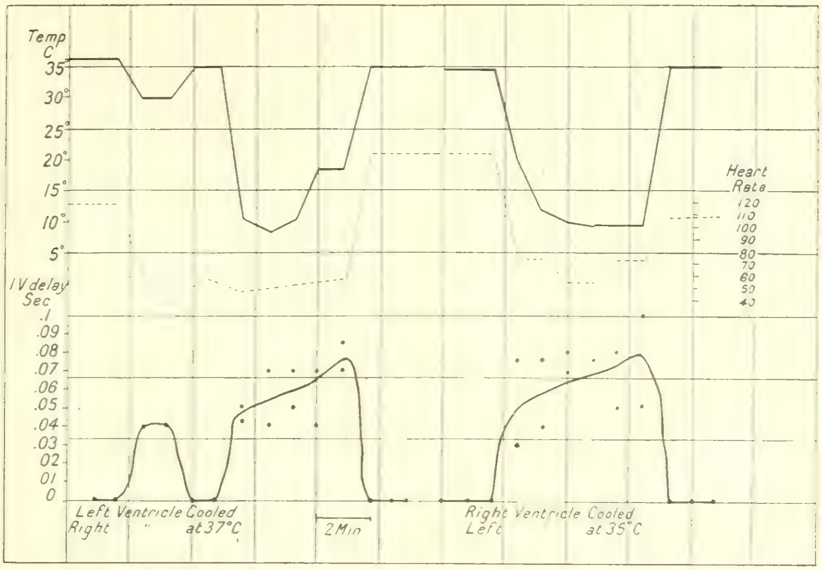


Fig. 2.—Showing the successive conditions and responses in experiment I. The upper curve indicates the intraventricular temperature of the left ventricle (first half of curve) and of the right (second half). Broken line indicates heart rate. The lower curve expresses the average interventricular lag or delay, the actual observations being expressed by dots.

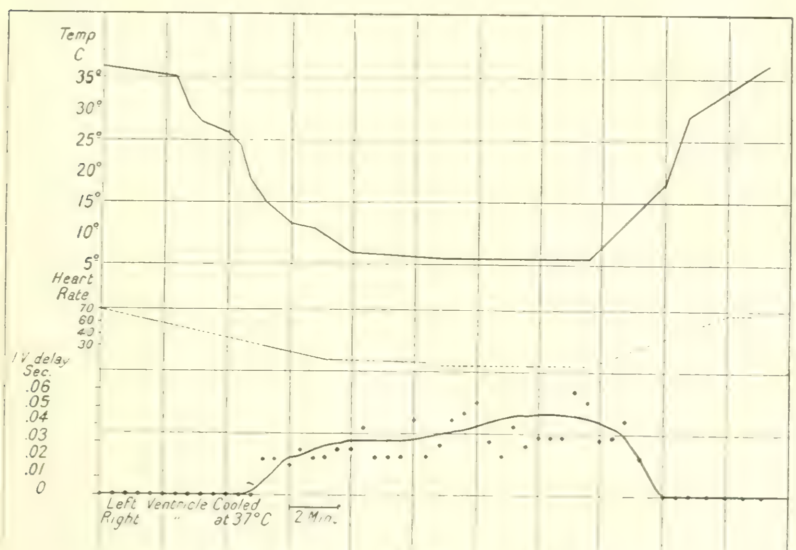


Fig. 3.—Showing course of experiment V. Left ventricle cooled. Right ventricle at 37° C throughout. The upper curve indicates the intraventricular temperature of the left ventricle. Heart rate indicated by broken line. The lower curve expresses the average interventricular lag or delay, the actual observations being expressed by dots.

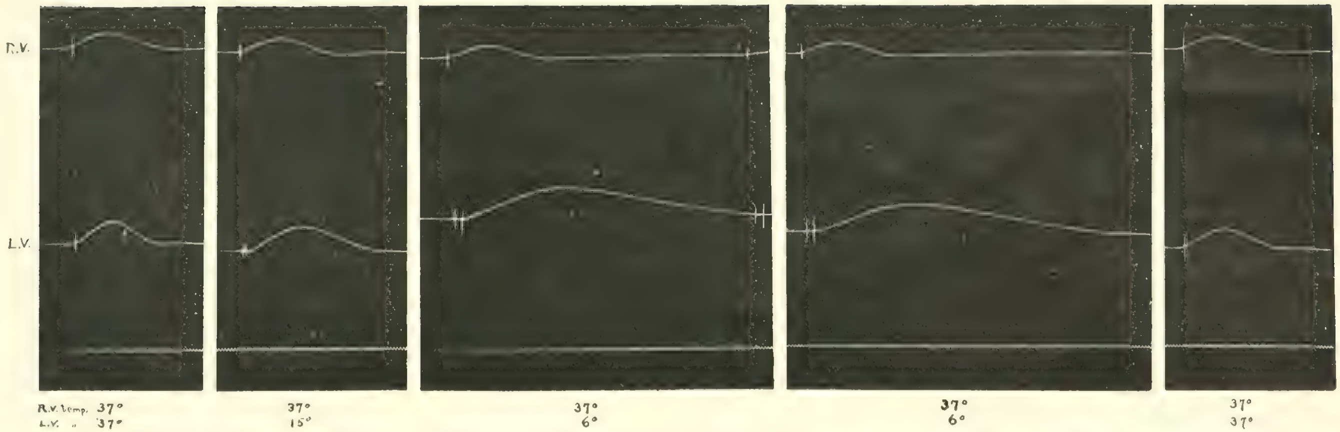


Fig. 4. Experiment V. Effect of unilateral interventricular cooling on the interventricular rhythm and co-ordination. Right ventricle (upper tracing) at 37° C. throughout experiment. Left ventricle cooled. Note the interventricular pause and the prolongation of systole and diastole on the cooled side of the heart. Upstroke: Systole. Downstroke: Diastole.

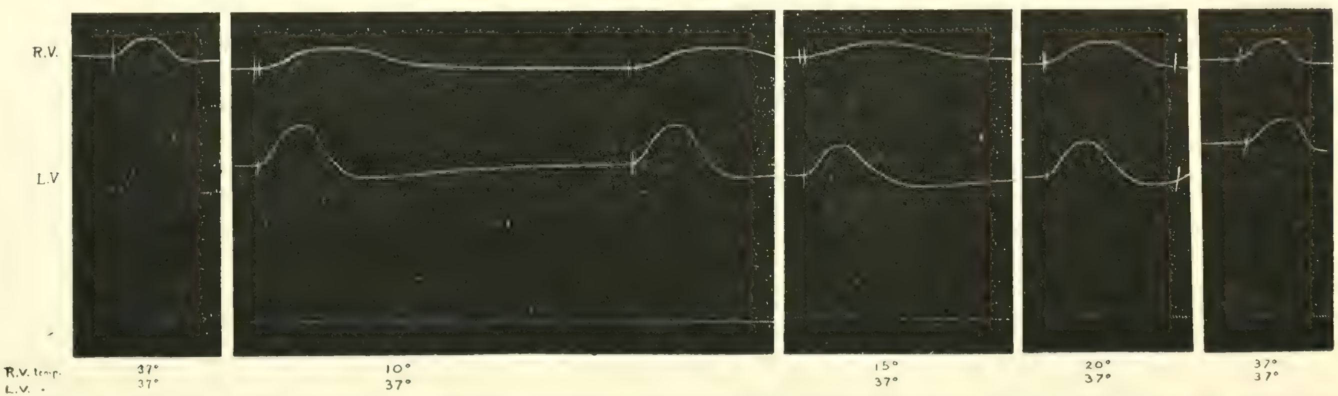


Fig. 5. Experiment VI. Right ventricle (upper tracing) cooled. Left ventricle at 37° C. throughout experiment. Note the interventricular pause and the prolongation of systole and diastole on the cooled side of the heart. Upstroke: Systole. Downstroke: Diastole.

to Ringer solution at temperatures of 10°, 18° and 30° C.. As in the experiments on the mammalian heart, the period elapsing between stimulus and response increases directly with the degree of cold applied.

Stassen[13] in experiments on the dog's heart describes, as a normal phenomenon, an interval of ·03 to ·04 sec. elapsing between the systole of the left and right ventricles. This observation is not supported by the present experiments on the cat's heart. In only one instance was so long an interventricular delay (·02 sec.) noted during the control periods with both ventricles at normal temperature. In all other experiments absolute synchronism prevailed unless the heart was subjected to unilateral cooling.

Effect on the time relations of systole and diastole. In addition to the disturbance of the interventricular rhythm, cooling of one of the ventricular chambers causes a marked alteration in the time relations of systole and diastole (Fig. 4 and 5). This inco-ordination is manifested by a progressive prolongation of the contraction and relaxation period on the cooled side. In some instances this effect is so pronounced that the ventricle at normal temperature has completed its kinetic phase (discharge and refilling) as the cooled ventricle is completing systole. As this effect depends on the reduced irritability and conductivity of the musculature, this inco-ordination is more pronounced if the cooling is somewhat prolonged. This disturbance, like the intersystolic delay, disappears immediately on return to normal temperature.

Effect on rate. As it is impossible, by the method employed, to prevent the gradual diffusion of cold to other parts of the heart, no significance can be attached to changes in rate. Without exception cooling of one side of the heart results in a gradual reduction in rate proportional to the degree of cold.

Conclusions.

Unilateral intraventricular cooling is followed by the appearance of an interventricular pause.

The pause thus induced is proportional to the degree of cold, the inception of systole in the cooled ventricle being progressively delayed until a maximum of ·05 to ·1 sec. is reached.

Where this delay exceeds ·02 to ·04 sec. it is probably to be explained by a depression of the conducting function of the Purkinje network. Below these limits depression of the main conducting strand may also be a factor in its production. In either case depression of muscular activity may also contribute to the production of the interventricular pause.

In addition to the disturbance of the interventricular rhythm, cold unilaterally applied induces a prolongation of the period of discharge and filling on the cooled side. This effect, proportional to the length of exposure

to the cooling agent, is considered an expression of depressed irritability and conductivity in the musculature of the cooled ventricle.

Proof is presented that interventricular arrhythmia can be induced by depressing the irritability of the musculature in one of the ventricular chambers. Whether such a condition of unilateral depression ever occurs as a pathological entity remains an open question.

BIBLIOGRAPHY.

[1] VON LEYDEN (E.). Archiv. f. path. Anat., 1868, XLIV, 365.

[2] VON LEYDEN (E.) AND BASSENGE (L.). Zeitschr. f. klin. Med. 1907, LXIV, 1.

[3] HEWLETT (A. W.). Archiv. of intern. Med., 1908, II, 139.

[4] RIEGEL (F.). "Zur Lehre von Herzirregularität," &c., Wiesbaden, 1891.

[5] HERING (H. E.). Deutsch. med. Wochenschr., 1903, XXIX, 381.

[6] HELSINGIUS (O. F.). Deutsch. med. Wochenschr., 1906, XXXII, 1406.

[7] BIGGS (L. N. H.). Brit. med. Journ., 1908, vol. I, 1419.

[8] BARKER (L. F.) AND HIRSCHFELDER (A. D.). Archiv. of intern. Med., 1909, IV, 193.

[9] SAIGO (Y.). Verhandl. d. deutsch. pathol. Gesells., Jena, 1908, XII, 165.

[10] EPPINGER (H.) AND ROTHBERGER (C. J.). Zentralbl. f. Physiol., 1911, XXIV, 1055.

[11] SCHMOLL (E.). Amer. Journ. med. Sci., 1908, CXXXVI, 663.

[12] HENDERSON (Y.) AND PRINCE (A. L.). Heart, 1913-1914, V, 217.

[13] STASSEN (M.). Archives internat. d. Physiol., 1907, V. 60.

VOLUNTARY ACCELERATION OF THE RATE OF THE HEART BEAT.

By JOHN FAVILL
(*Chicago*),

AND

PAUL DUDLEY WHITE
(*Massachusetts General Hospital, Boston*).

THIRTEEN individuals possessing the power to accelerate at will their heart rate have been recorded, one by Tuke[6] in 1872, five by Tarchanoff[5] in 1884, one by Pease[4]* in 1889, five by Van de Velde[7] in 1897 and one by Koehler[3] in 1914. Electrocardiograms were taken in the last mentioned case.

There has been considerable discussion as to the mechanism of this acceleration, especially as to whether it is purely a removal of vagal influences or an accelerator nerve action primarily.[2 3 5 7] Evidence in general has favoured the latter view. Koehler omitted the important test with atropin because of the development of cardiac irregularity in his case ; the other investigators make no mention of the test.

A study of the accelerating mechanism of one of us (J.F.) was undertaken in order to determine if there is a change of pace-maker or other change of mechanism during the acceleration. An Einthoven string galvanometer of the Cambridge pattern containing a silvered glass fibre of 2,600 ohms resistance has been used in our investigation.

The voluntary acceleration of the heart rate in our case begins almost immediately after the subject has willed it to begin and one second after the word is given by the observer. (Fig. 3.) It does not reach its maximum at once, several beats occurring before the high mark is attained. The degree of acceleration is greater the stronger the impulse and the fresher

---

* The subject of the investigation of Pease in 1889 has recently (February the 26th, 1915) been electrocardiographed by one of us during his voluntary acceleration of the pulse rate. He had not performed the feat for something over twenty years and yet he proved his capacity on the very first trial and on the second trial his pulse rose after a few beats to a rate of 113, while before the experiment it had been 80. His maximum acceleration twenty-six years ago was 27 beats per minute. No note was made in 1889 of the condition of the pupils during the acceleration ; at present there is distinct and rapid dilatation of the pupils synchronous with the voluntary acceleration. The electrocardiograms accord with those taken of J. F., the subject of the present communication.

the condition of the subject ; the latter fact has been remarked by all former observers of similar phenomena. The greatest acceleration recorded electrocardiographically in our case has been one of 63 beats, from a rate of 98 to one of 161. (Fig. 4.) The greatest acceleration remembered by our subject was one of 96 beats in 1912, when, under the observation of Drs. Coller and Barton, the pulse rate rose from 104 to 200, the paroxysm lasting for 30 seconds, longer than in any other trial. The least increase in rate, except while under the influence of atropin, has been 30 beats, from a rate of 90 to one of 120. Intermediate increases have occurred, as of 40 beats (rate of 82 to one of 122) and of 47 beats (rate of 75 to one of 122).

As a rule in the cases previously recorded the maximum acceleration has been considerably less (usually 15 to 30) ; in one individual, however, (Dr. S. Tarchanoff's third case) an increase of 75 beats per minute was attained, from a rate of 85 to one of 160. In the period of our greatest acceleration, recorded electrocardiographically, about 15 beats occurred more and more quickly up to the maximum ; then after three or four beats at the fastest rate slowing began. Accompanying the extreme acceleration a general deflection of the electrocardiographic fibre occurred (Fig. 4) coinciding with muscular effort and holding of breath, but with the lesser grades the respiration was continued and there were no visible muscular movements and very little evidence of any electrocardiographically. (Fig. 3.) During forced respiration and also during the Valsalva experiment there was evidence of the vigorous muscular movements on the electrocardiograms. (Fig. 5.)

Effects of voluntary acceleration, exercise and atropin on electrocardiographic deflections.

Voluntary acceleration affected the auricular deflection P neither in shape, amplitude nor duration. Fortunately this deflection in our case normally has three subdivisions occurring as peaks on the upstroke. These three peaks are clearly discernible in the P during the acceleration. (Fig. 3.) The P-R interval remained unchanged. R and S as a rule decreased in amplitude, during the extreme acceleration by about one-third (for example R equalling 14×10^{-4} volts becomes 9×10^{-4} volts). The T increased slightly in amplitude and rose from the S a little more abruptly than normally. There was very little decrease in the interval from the beginning of R to the end of T with the acceleration. Diastole was at times so shortened that the P fell upon the previous T. (Fig. 4.)

Exercise, consisting of vigorous running, had no appreciable effect on the P, R, or S waves but did markedly change the T although the rate was raised only 25 beats (82 to 107) which was less than that of the voluntary acceleration. The T increased more than 100 per cent. in amplitude and rose sharply after the S. Also the interval R to the end of T was definitely shortened as compared with that during voluntary acceleration. The

diastolic arching upward of the electrocardiogram (*U* wave) was more obvious immediately after exercise than before. (Fig. 6.) Gasser and Meek[1] after studying the mechanism by which muscular exercise produces acceleration of the heart, conclude that the primary rise in rate is due to the decrease in vagal tone but that the action of the accelerator nerves is superimposed on the vagal inhibition as the acceleration increases.

Atropin in the dosage of two-thousandths of a gram subcutaneously increased the heart rate from 82 to 105 in one half hour. The *P*, *R* and *S* remained unchanged, the *T* slightly more abrupt and increased in amplitude and the interval *R* to end of *T* decreased appreciably. (Fig. 7.)

Respiration. Forced inspiration increased the rate from 86 to 99 and increased the height and acuteness of *T* while forced expiration reduced the rate to 73 and blunted the *T* (Fig. 5). During quiet breathing considerable sinus arrhythmia occurred.

Forcible attempts to expire with glottis closed increased the heart rate from 86 to 95, decreased the amplitude of *R* and increased *S* (Fig. 5). Vagal pressure, right sided, up to the point of pain slowed the heart from 86 to 67. (Fig. 8.)

Voluntary acceleration after atropin. Two tests were made. On the first occasion one half hour after the subcutaneous injection of atropin gr. 1/30 and at the height of its action as evidenced by the extreme dryness of the mouth, by the inability to slow the heart by vagal pressure and by the increase of 23 beats in the pulse (82 to 105) the word was given to accelerate the heart beat. A response followed, the rate rising to 125 (increase of 20 beats). One hour after the atropin injection voluntary acceleration increased the rate from 98 to 122 (24 beats). (Fig. 9.) On the second occasion, forty-eight minutes after the subcutaneous injection of atropin gr. 1/30, voluntary acceleration of the pulse was attempted and resulted in an abrupt increase of the pulse rate from 140 to 168 per minute (Table). With the removal of vagal action the voluntary increase in rate must be the result of accelerator nerve action. Ordinarily it may result entirely from accelerator action or it may be composed of the superimposition of the action of the accelerators on that of the withdrawal of the vagi, as Gasser and Meek[1] conclude in regard to the mechanism of acceleration during violent exercise.

Further observations. Radial pulse tracings taken with the Mackenzie ink polygraph show a gradual onset of the voluntary acceleration with at first a decrease in amplitude but shortly followed by a marked increase with considerable dicrotism persisting over a stretch of beats after the paroxysm has ceased. (Fig. 1.) Koehler[3] reported the presence of a marked sinus arrhythmia with very pronounced dicrotism ; in our tracings these conditions are found. The pulse is slower immediately after the paroxysm than at any other time.

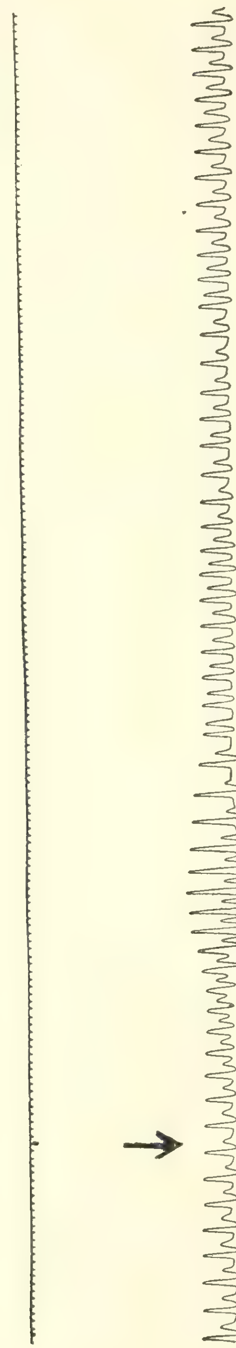


Fig. 1. Radial pulse tracing taken during a short paroxysm of voluntary acceleration. Arrow marks the time at which the word was given to accelerate the pulse. The effort was sustained for a few seconds only. Time interval = 0·2 sec..

TABLE.

VOLUNTARY ACCELERATION OF THE PULSE DURING THE ACTION OF ATROPIN.

TIME.	PULSE RATE.	SYSTOLIC BLOOD PRESSURE.	FURTHER OBSERVATIONS.
3·00 P.M.	92	125 mm. Hg.	
3·02 „			Atropin gr. 1/30 subcut.
3.15 „	110	135 „	Dryness of mouth begins.
3.30 „	138	122 „	Pupils slightly dilated.
3.45 „	140	110 „	Throat very dry.
3.50 „	168	138 „	*Voluntary acceleration.* Marked and sudden increase of dilatation of pupils with voluntary acceleration of pulse.
4.00 „	132	105 „	Pupils slightly dilated as at 3.30 p.m.
4.15 „	120	115 „	
4.30 „	112	112 „	
4.45 „	104	118 „	
5.00 „	100	112 „	Throat less dry.
5.15 „	100	118 „	
5.30 „	94	115 „	
5.45 „	92	118 „	
6.00 „	88	120 „	

Blood pressure. There was in our case as in those of Tarcharnoff, Pease, and Koehler a definite rise in blood pressure following the onset of the voluntary tachycardia. On both of the first two occasions the systolic and diastolic pressures increased. On the first occasion the systolic rise was from 124 to 146 mm. mercury and the diastolic from 66 to 90.* On the second occasion with the pressure already elevated from excitement the rise was from 140 to 160 mm. systolic and from 80 to 110 diastolic. Readings were taken with the Mercer mercury sphygmomanometer. On the third occasion during the action of atropin the voluntary acceleration of the pulse was accompanied by a rise of systolic blood pressure from 110 to 138 mm. Hg. (Table).

Fluoroscopic examination made by Dr. Case of St. Luke's Hospital, Chicago, before, during, and after a paroxysm of voluntary tachycardia showed no change in the cardiac outlines.

* Shortly after the cessation of the paroxysm the systolic pressure was 122 and the diastolic 70 mm. mercury.

Dilatation of the pupils occurred distinctly and rapidly within one second after the word to accelerate the pulse was given. This dilatation occurred also with the voluntary acceleration of the pulse undertaken while the subject was under the influence of atropin (Table).

Changes in respiration and voluntary acceleration of the pulse have very little relationship in our case, a fact already shown in other cases by Tarchanoff, Pease, Van de Velde and Koehler. In our case the paroxysm might be accompanied by rapid or slow, deep or shallow respirations or by apnœa.

Muscular action came into play so far as we could observe only in the instance of great effort in producing the acceleration (as during the increase of 63 beats).

Slight sweating of the palms occurred during the paroxysms, but there was no flushing of the skin or goose flesh.

The effect of a hot bath on the normal pulse rate in our case consisted of a slight acceleration not over 10 or 15 beats per minute.

Previous history and subjective phenomena.

There has never been any organic heart disease so far as known. Beginning at the age of fifteen, occasionally an increased pulse rate from slight cause, alarm or exertion, was noticed but was never distressing. Mere examination of the heart itself was sufficient cause for an increase of 20 beats a minute. Cross-country running before and after the age of twenty produced no cardiac symptoms, even when seven miles were covered in forty minutes. At the age of 22 the exertion of climbing a small mountain raised the pulse rate to 190. A year later in 1910 a climb of the Breithorn in Switzerland was accomplished after several days of tennis and strenuous walking. The preliminary day's climb caused some precordial pain and during the night an alarming attack of palpitation, apparently a paroxysm of tachycardia, occurred which lasted 20 seconds. This was the only time that such a thing has happened. On the following day the summit was reached. The pulse was between 140 and 160 during the day. After a week's rest similar exertion produced no effect.

In 1911 the sensation which has since been found to accompany the voluntary acceleration was induced for no known reason and occasionally repeated in the years following. One day by chance in 1913 the voluntary acceleration of heart rate was discovered when the sensation was induced while the pulse was being felt. The process was repeated and demonstrated to many people during the next few months. It has been attempted less often during the past year or more but no difficulty has been experienced in bringing it on even after a lapse of several months.

On two occasions the ability to accelerate the pulse has been serviceable to its possessor. Once in a condition of great fatigue in a hot operating room

and again while watching cattle killed in a great packing plant for the first time sensations of impending syncope were felt. On each occasion the voluntary acceleration (with its rise of blood pressure) was induced and the feeling of faintness vanished at once.

It seems to be impossible to describe the sensations attending the production of the acceleration any more than one can describe the conscious effort in voluntary movement of the arm. With the onset of the tachycardia there is a feeling of "fullness" or tingling over the whole body. A mild exhilaration follows in a few seconds and moderate fatigue results if the paroxysm is induced several times successively or for any period longer than a very few seconds. The acceleration is dependent on a distinct effort of the will and the strain is as tiring as that produced by holding up a heavy weight ; it is not a succession of efforts but one that is continuous. Distinct relief is felt with the cessation of the acceleration.

The unusual muscle control emphasised by Tarchanoff and minimized by Van de Velde and Koehler is present to a certain degree in our case and consists of the ability to move the right ear and to flex the terminal phalanges of the fingers.

Physical examination of J.F. on December 4th, 1914, shows a healthy individual with heart normal in size and sounds except for a short soft systolic murmur heard at the base.

Summary.

Voluntary acceleration of the heart rate has been studied in an individual showing the ability to accomplish it in a remarkable degree.

There is no apparent change in the situation of the pacemaker with the onset of the acceleration.

Evidence is given to show that the voluntary increase of the heart rate is the result in great part at least of the action of the accelerator nerve mechanism and that it is not due solely or chiefly to the withdrawal of vagal action.

1. The administration of atropin in a large dose produces not one half of the increase in pulse rate which results from the voluntary acceleration.

2. The ability to accelerate the rate of the heart beat persists after the removal of vagal action by atropin.

3. Synchronous with the acceleration of the pulse there is distinct dilatation of the pupils and definite increase in systolic and diastolic blood pressure even while the subject is under the influence of a large dose of atropin.

4. The changes in the electrocardiographic deflections during the acceleration are those which are known to occur when the sympathetic nerves are stimulated experimentally.*

* See Lewis and Cotton, Proc. Physiol. Soc., June 28th, 1913.

BIBLIOGRAPHY.

[1] Gasser (H. S.) and Meek (W. J.). Amer. Journ. of Physiol., 1914, xxxiv, 48.

[2] Hunt (R.). Amer. Journ. of Physiol., 1899, ii, 395.

[3] Koehler (M.). Archiv. f. d. ges. Physiol., 1914, clviii, 579.

[4] Pease (E. A.). Boston med. and surg. Journ., 1889, cxx, 525.

[5] Tarchanoff (J. R.). Archiv. f. d. ges. Physiol., 1885, xxxv, 109.

[6] Tuke (D. H.). "Illustrations of the Influence of the Mind upon the Body in Health and Disease, designed to elucidate the Action of the Imagination." London, 1872.

[7] Van de Velde (Th. H.). Archiv. f. d. ges. Physiol., 1897, lxvi, 232.

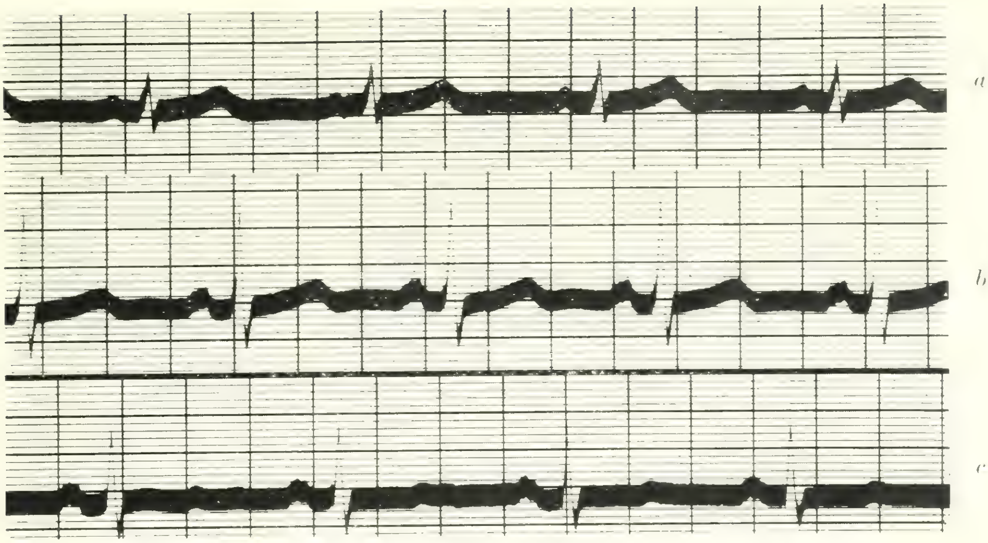


Fig. 2. Normal electrocardiogram of J. F. (*a*) Lead *I*. (*b*) Lead *II*. (*c*) Lead *III*. Abscissæ = 0·2 sec., ordinates = 10^{-4} volts. Similar co-ordinates in succeeding figures.

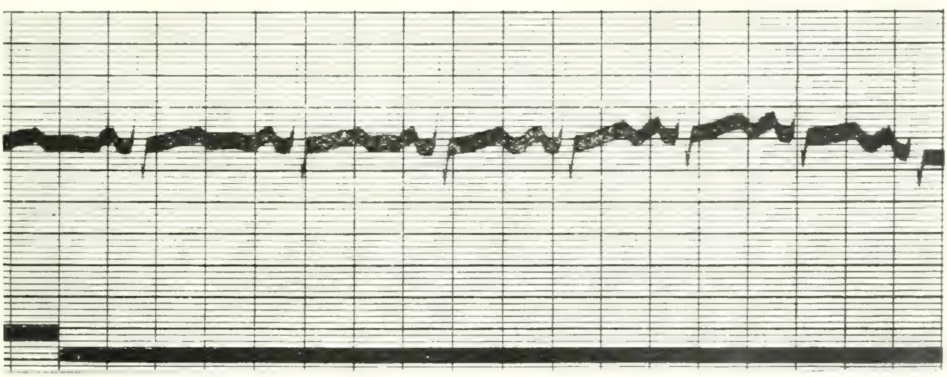
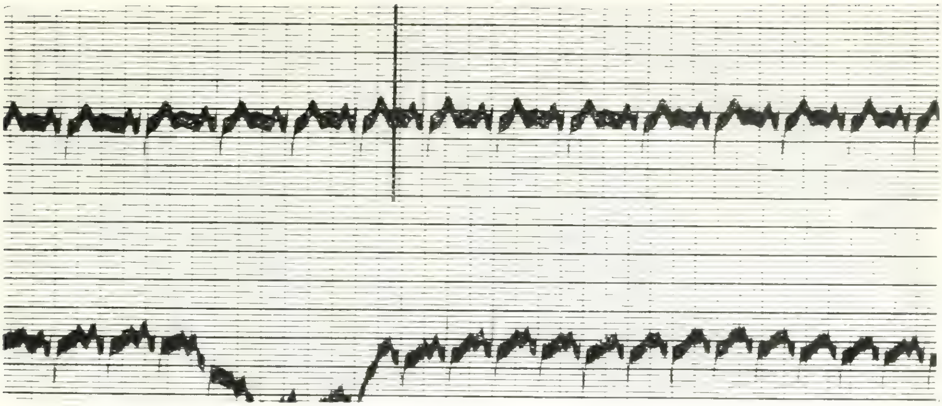


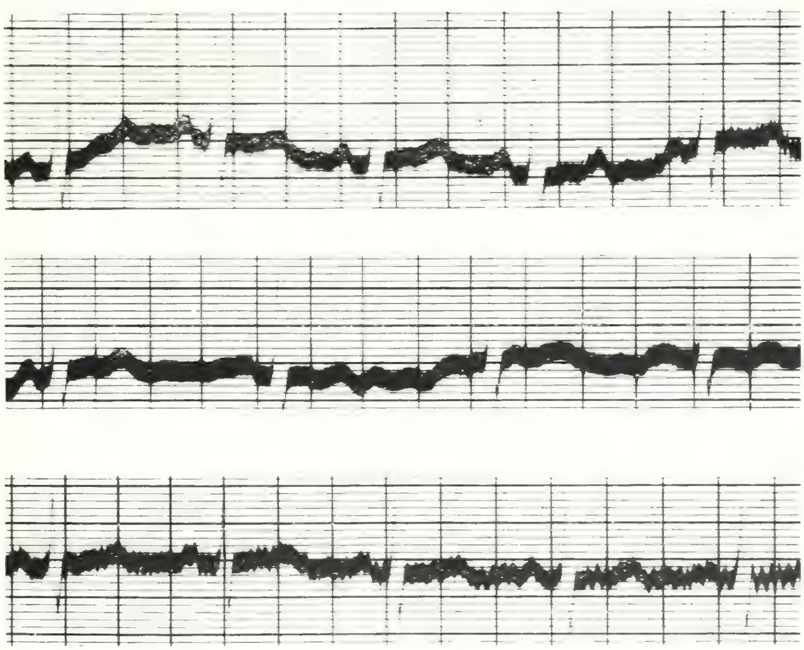
Fig. 3. Lead *II* during onset of voluntary acceleration of the pulse. Signal indicates the time at which the word of command was given.



a

b

Fig. 4. Lead *II* in both records.
(*a*) Preceding onset of the acceleration.
(*b*) Soon after the onset and at the height of the acceleration.



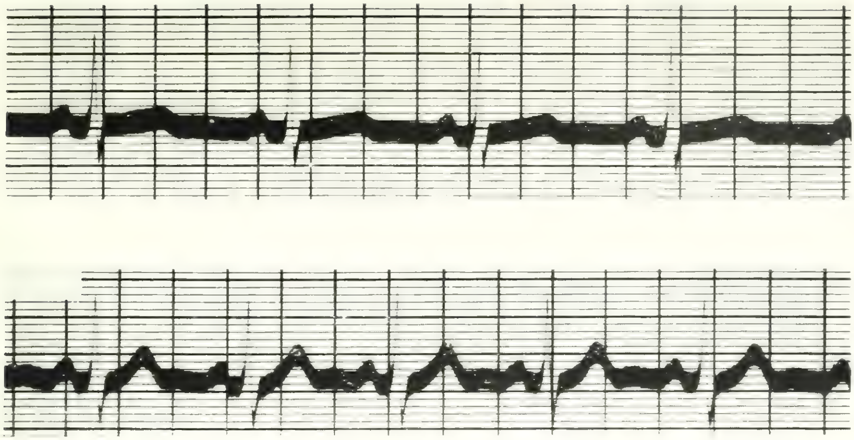
a

b

c

Fig. 5. Lead *II*. (*a*) During forced inspiration. (*b*) During forced expiration. (*c*) During forcible attempt to expire with glottis closed

185—6



a

b

Fig. 6. Lead *II*. (*a*) Before exercise. (*b*) Immediately after exercise (vigorous running).

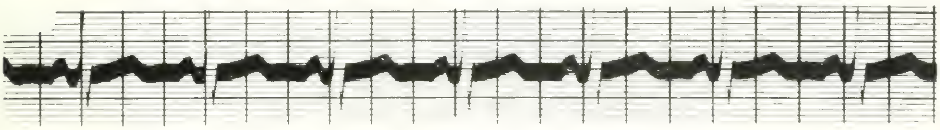


Fig. 7. Lead *II*. Twenty-two minutes after the subcutaneous injection of atropin, gm. ·002.

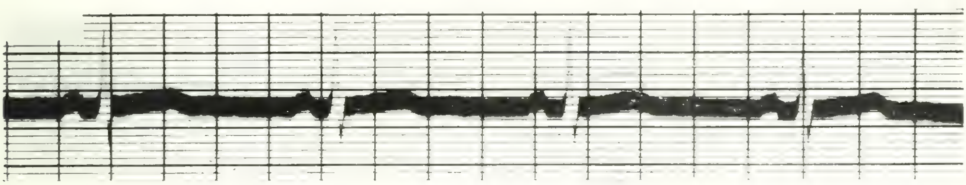
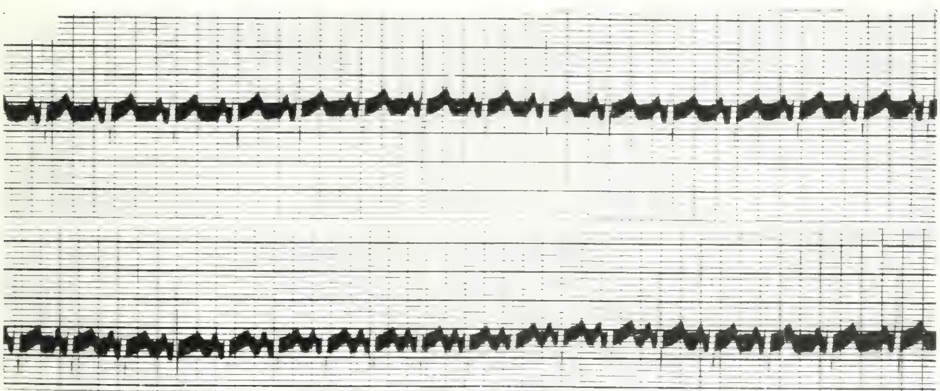


Fig. 8. Lead *II*. During right vagal compression.



a

b

Fig. 9. Lead *II*. (*a*) Sixty minutes after atropin injection. (*b*) Voluntary acceleration one minute later.

ELECTROCARDIOGRAPHIC STUDIES IN NORMAL INFANTS AND CHILDREN.

By EDWARD B. KRUMBHAAR and HORACE H. JENKS

(*From the Department of Medicine, University of Pennsylvania and The Pepper Laboratory of Clinical Medicine*).

ELECTROCARDIOGRAPHIC studies of congenital and acquired heart disease in infancy and childhood have accumulated with considerable rapidity in the past few years. Furthermore the interpretation of the records obtained has frequently gone beyond the mere analysis of cardiac arrhythmias to include such questions as the relative predominance of one or the other ventricle, the significance of changes in the *T* wave or other portions of the ventricular complex. On attempting, however, to interpret some anomalous electrocardiograms obtained by us in young children, we were surprised to find that the establishment of normal standards for early life has received comparatively little attention. Very few examples were available from infants and these usually in only one of the three customary leads.

Lewis[4] states that "relative preponderance of the right ventricle during the first few weeks of extrauterine life is physiological; the outlines of the electric curves in the new born child are almost constant; . . . . The normal adult forms of initial deflections are assumed between the ends of the second and third month of extrauterine life." His curves from a child two hours after birth, and from the same child six weeks later (showing relatively less right-sided preponderance) are about the only satisfactory data to be had on this subject in English.

Funaro[1] in 1908 studied the electrocardiograms of forty-five infants and children, but many of his subjects were abnormal, and unfortunately only Lead *I* (right arm to left arm) was taken. Although this procedure coupled with a different nomenclature is still upheld by Kraus and Nicolai, it is obviously an inadvisable departure from the method originally recommended by Einthoven and most generally in use. As *S* was greater than *R* in many of Funaro's records, it appears that he too found a preponderance of the right ventricle, though Nicolai at the time attributed this phenomenon either to left ventricle hypertrophy or to the fact that the infant's heart lies more horizontally than that of the adult. Funaro also states that the deflections were very small in the first few days of life, but quickly became

larger in the first month. Such findings, however, are always open to the criticism that the numerous factors entering into the production of a properly standardized electrocardiogram may not have been properly controlled.

The effect of increasing age on the form of the electrocardiogram has been studied by Linetzky[6], who found that *R* increased and *T* decreased with age, whereas *P* was unchanged. Infants and children, however, were not included in this study as a separate group.

The most satisfactory German study of this subject is by Hecht[2]. Included in his exhaustive work on the mechanism of the heart action in childhood, are tables of the values of the *P* (*A*), *R* (*J*), and *T* (*F*) deflections in Lead *I* from 26 newborn infants, 11 under one year of age, 4 young and 26 older children.* These corroborate Lewis' and Funaro's findings that S^1 (*i.e.*, the *S* wave in Lead *I*) is relatively deep in infancy, but in the different subjects of his series it becomes less than R^1, at different periods between the third and seventh month. A split *P* wave he found only once; split *R* and *S* waves occurred more frequently, especially in the older children. The *T* wave he found small in infancy, and inconstant in Lead *III* at all years. The *P-R* interval of the newborn varied from 0·09 to 0·12 sec. (except in two instances of 0·14 sec.), that of the infants from 0·07 to 0·12 sec., that of the young children from 0·11 to 0·15 sec., and that of the older children from 0·10 to 0·16 second. Numerous reproductions of records make this a valuable work for comparative reference.

Methods.

Our studies have been made on 42 normal subjects whose ages range from immediately after birth to 11 years, and on several children exhibiting one or other form of heart disease. (These pathological studies will be reserved for a later communication). Platinum strings (Edelmann galvanometer) of 3120 ohms and 3500 ohms resistance, and of less than 0·02 second deflection time were used. Although the body resistance in ohms was always ascertained, the string tension was so adjusted that 3 millivolts gave 3 centimetres excursion with an arbitrary 2,000 ohms added resistance in circuit. In some cases, the string was so slackened that 1 millivolt gave 2 or 3 centimetres excursion, but in no case did the deflection time exceed 0.02 second. In the following table all figures are calculated on the basis of the standard string tension of 1 cm. for 1 millivolt. Flexible German silver electrodes between pads moistened in strong salt solution were applied to the wrists and left ankle. Later, a copper plate electrode firmly attached to an infant's shoe, with binding post projecting through the sole, was found to be more serviceable and reliable. When the child was too young to recline in a chair insulated by rubber feet, we have laid it upon a table covered with dentist's rubber tissue. In order to obviate any deflection of currents by the child crossing arms or legs, the rubber tissue also was wrapped about arms and legs. The "body resistance" was found to vary between

* Many of these, however, were not healthy children.

TABLE I.—GIVING THE VALUES OF ELECTROCARDIOGRAPHIC DEFLECTIONS IN MILLIVOLTS, THE PULSE RATE AND P-R INTERVAL.

Age.	Name.	Sex.	P 1	P 2	P 3	Q 1	Q 2	Q 3	R 1	R 2	R 3	S 1	S 2	S 3	T 1	T 2	T 3	Rate.	P.-R. Interval.
Before Cord.	G.N.	F.	·1			·05			·6			1·4			·2			160	0·11
After Cord.	G.N.	F.	·05	·1	·1	0	0	·6	·4	1·2	1·7	·8	·6	·2	·1	·1	0	130	0·14
10 hours	M.R.	M.	·02	·01	0	0	·2	·1	·5	·1	·2	·3	0	0	0	0	·01	125	0·11
10 ,,	R.H.	M.	·1	·15	·15	0	·4	·2	0	1·0	1·3	·6	1·0	·8	·1*	·15	·2	100	0·12
11 ,,	P.L.	M.	?	·1	?	?	·05	0	·1	·4	·3	0	·1	·1	?	?	?	118	0·12
24 ,,	C.L.	F.	·01	·02	0	0	0	0	·01	·2	·4	·4	·5	·1	·01*	·01	?	130	0·12
26 ,,	F.N.	M.	·05	·1	·05	0	·01	·2	·2	1·0	1·3	·6	·02	·05	·2	·1	·1*	145	0·08
3 days	C.T.	F.	0	·05	·05	0	·1	·2	·05	·5	·7	·3	·5	·4	·05	·1	·05*	96	0·12
5 ,,	G.N.	F.	0	·1	?	0	·2	·3	·2	·5	1·7	·3	·3	·3	0	·1	0	118	0·10
6 ,,	C.L.	M.	·1	·2	·1	0	·2	·2	·3	·3	·5	·6	·3	·1	·2	·2	0	120	0·12
14 ,,	G.N.	F.	·1	·1	·1	·1	·2	·4	·3	·6	1·0	·5	·4	·4	·1	·1	·05	136	0·12
20 ,,	W.E.	M.	·05	·1	?	0	0	·1	·1	·15	·3	·3	·1+	·1	·1	·1	?	166	0·10
3 weeks	S.E.	F.	·1	·2	·1	0	·3	·4	·5	1·2	1·4	·6	·2	·05	·2	·3	·1	120	0·12
3 ,,	O.R.	M.	·1	·1*	·1	·05	·2	·2	·4	·7	·7	·5	·1	·2	·1	·1	·2	132	0·16
6 ,,	D.R.	M.	·1	·15	·1	0	·4	·5	·5	1·0	·9	·6	·5	·3	·2	·4	·3	85	0·12
7 ,,	H.S.	M.	·1	·2	·05	0	·2	·2	·3	1·6	1·0	·5	·1	0	·2	·2	?	150	0·11
8 ,,	C.E.	M.	·1	·2	·1	0	·1	·4	·9	1·2	·9	1·0	·4	·2	·2	·3	·1	100	0·12
9 ,,	M.A.	M.	·15	·2	·1	0	·1	·3	·9	1·4	·6	·8	·2	·2	·2	·3	?	155	0·12
10 ,,	C.M.	F.	·1	·1	·1	·2	·2	·2	·5	·8	·5	·5	·4	·4	·15	·2	·1	140	0·11
14 ,,	C.M.	F,	·1	·2	·05	·2	·3	·1	·5	·9	·5	·4	·4	·2	·2	·2	·1	120	0·12
17 ,,	M.S.	F.	·1	·2	·1	·1	·6	·6	·7	1·8	1·0	·5	·4	1·6	·3	·4	0	148	0·11
5 months	R.H.	M.	·1	·1	·05	·6	·5	·6	1·4	1·6	·9	·3	·4	·2	·6	·4	·1*	134	0·12
5½ ,,	C.L.	F.	·1	·15	0	·05	·05	·4	·8	1·1	·6	·5	·4	·1	·2	·4	·5*	130	0·12
6 ,,	C.D.	M.	·1	·2	·1	0	0	·8	1·8	1·4	1·1	1·1	·4	0	·6	·5	0	130	0·10
6 ,,	R.H.	M.	·15	·2	·1	·6	·4	·5	1·6	1·6	·8	·2	·3	·2	·6	·3	·1	160	0·12
6½ ,,	C.L.	F.	·15	·2	0	·1	·15	·4	·8	·8	·3	·4	·5	0	·5	·3	·1	140	0·12
6½ ,,	G.N.	F.	·1	·2	0	·3	·6	1·0	1·6	1·4	1·4	·8	·3	·05	·5	·5	·3	132	0·13
7 ,,	L.W.	F.	·1	·1	0	0	·3	·6	·7	1·8	1·2	·5	·4	·3	·3	·2	·1	160	0·12
13 ,,	B.Y.	M.	·1	·1	·1	·1	·6	1·	·6	·8	·9	·2	0	0	·4	·2	·2	135	0·15
19 ,,	D.N.	M.	·1	·2	·05	·3	·6	·4	·9	1·3	·8	·5	·4	0	·7	·4	·2*	130	0·13
20 ,,	B.M.	M.	·1	·1	·1	0	·2	·2	·8	1·0	·7	·7	·5	·3	·2	·1	·1	110	0·12
24 ,,	M.S.	M.	·1	·15	·05	0	0	·4	·1	1·0	·6	·3	0	0	·3	·2	·1	112	0·14
25 ,,	G.A.	F.	·2	·2	·1	0	·2	·3	·6	·7	·6	·4	·2	0	·3	·3	·1	135	0·13
5 years	F.A.	F.	·15	·2	?	·2	·1	·3	·9	1·2	·5	·2	·1	0	·15	·2	?	140	0·13
6 ,,	M.A.	F.	·2	·3	·1	0	·05	·3	1·2	1·4	·4	·25	·1	·3	·3	·2	·1	106	0·13
7 ,,	P.I.	M.	·2	·2	·1	·4	·3	0	1·6	1·3	·3	0	0	0	·4	·4	·1	88	0·13
8 ,,	K.M.	M.	·2	·2	·1	·1	0	0	1·1	·8	·5	·15	·4	·6	·5	·4	·1	90	0·14
8½ ,,	C.N.	M.	·1	·2	·1	·4	0	0	1·4	·7	·5	0	·4	·7	·3	·3	0	110	0·16
10 ,,	S.H.	M.	·2	·3	·1	·2	·3	·4	·8	·6	1·0	·7	·2	0	·4	·5	·25	80	0·16
10 ,,	M.E.	M.	·2	·25	·1	·15	·2	·1	1·0	1·2	·6	·15	·4	·3	·25	·2	·17	104	0·16
10 ,,	H.N.	F.	·5	·2	·1	0	0	0	1·0	2·1	1·4	0	0	0	·4	·4	·1	110	0·14
13 ,,	J.N	M.	·15	·2	·1	·3	·1	0	1·6	1·0	·2	0	·8	·8	·6	·7	·1	100	0·15

* Inverted.

700 and 1,400 ohms in different subjects apparently without regard to age. It was frequently difficult to get satisfactory curves on account of the restlessness of the infant under these conditions. This restlessness undoubtedly also affected the heart rate and may have had a slight effect on the P-R interval, but as similar records at slower heart rates were obtained when the child happened to be asleep, we do not believe that the form of the complexes or P-R interval was materially changed by this increase in rate. As we were unable at that time to employ a rotary time marker, measurement of time intervals was unavoidably less accurate, but the margin of error was far too slight to affect any of our deductions. As Hecht[2], Hoffmann[3], and others have found changes in the form of the electrocardiogram due to changes in position, the infant was placed always upon its back. In a few cases, however, records were also taken with the infant lying first on the left and then on the right side, without materially affecting the form of the complexes. The small changes thus produced (a millimetre or less in the height of R or S) were less than the changes caused by respiration in the same record.

Results.

The values for the different waves have been arranged according to age in table 1 :—

Preponderance of right ventricle.

It will be seen that the findings of other authors in regard to right ventricular preponderance are here confirmed. It is uniformly present at birth (Fig. 2) and in the early weeks of infancy, and gradually disappears in the second or third month. The various factors, however, change at different periods : thus R^2 becomes greater than R^3 about the sixth week, but S^1 persists abnormally large for several months (Fig. 3). It usually becomes smaller than R^1 (a convenient measuring point) about the eighth to tenth week. By the sixth month, the infant's electrocardiogram has become practically the same as that of the adult (Fig. 4). These changes are illustrated graphically by the accompanying composite curves from the three leads in the different age groups (Fig. 1).

Q wave.

Another striking attribute of most of these curves is the relatively large size of Q, especially in Leads *II* and *III*. The average size of Q in adults is less than 1 mm., whereas in most of the subjects of this series, it is not only actually larger but larger proportionately to the other waves. This is especially noticeable in Lead *III* of the younger subjects, although in a few cases, Q was highest in Lead *II* and four times in Lead *I*. An explanation of these phenomena is found in the recent evidence furnished by Lewis.[5] Q in Lead *I* of the human electrocardiogram probably represents spread of activity in the left ventricle, whereas in Leads *II* and *III* of the human electrocardiogram, Q probably represents spread in the right

COMPOSITE ELECTROCARDIOGRAMS.

Age Group. *Lead I.* *Lead II.* *Lead III.*

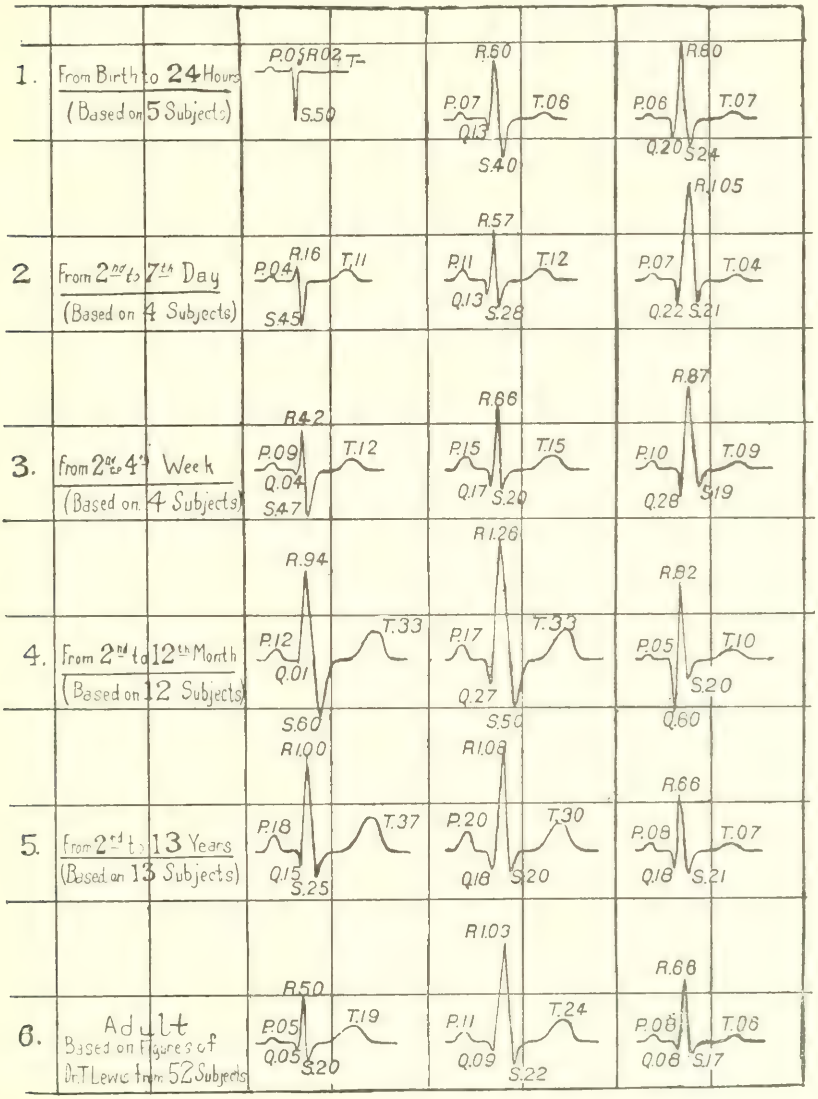


Fig. 1. Composite electrocardiograms arranged according to age groups. The height of each deflection is drawn to scale, from the average figures obtained for each deflection from each group. The numerals opposite each letter refer to the values in millivolts.

ventricle. In the present series, therefore, the behaviour of Q is added to the other signs of right ventricular preponderance in the younger subjects. Confirming Lewis' views, it is interesting also to note that the four cases in which Q^{1} is biggest (all between 7 and 13 years of age) were the only ones examined in which the other commonly accepted signs of left ventricular preponderance were also present (see table 1).

T wave.

The T wave has invariably been found absent in the first week of life. In one case in which opportunity was offered to make a record before the umbilical cord was cut, a distinct T wave was present, which almost disappeared after cutting the cord. If this were found to be constant, it would afford interesting opportunity for speculation as to damage done the heart by this procedure. After the first three weeks of life, the T wave reaches a proper proportionate size. It is largest in Lead *II* and lowest and frequently inverted in Lead *III*.

Various abnormalities, such as splitting of R and S, have occasionally been found in the normal infant and child just as in the normal adult. On account of their lack of clinical significance, however, we do not discuss them further. The U wave was but rarely found.

The actual size of the units of the ventricular complex has shown considerable variation in the different subjects, and we have not been able to demonstrate definite relations of these variations to any given factors. In spite of the fact, therefore, that the tension of the string galvanometer was properly standardized, and the resistance of the subject and circuit estimated and allowed for in each case, we are inclined to attribute these variations to factors that we were unable to control. The most probable explanation of the production of the smaller deflections is that after the estimation of the resistance of the infant, its sometimes violent movements may have sufficiently dislodged the electrodes to cause a considerable and unmeasured increase in resistance.

P-R interval.

The interval between the onset of auricular and ventricular activity has also been studied. As Q is unquestionably a part of the ventricular complex, we have taken the P-Q time (when Q is present) as the most accurate measure of this interval, retaining for convenience the term P-R interval. In the absence of Q, as R is then the first sign of ventricular activity, the P-R time has been taken as affording an accurate basis of comparison. From the table, it will be seen that in early infancy the P-R interval is distinctly shortened ; being, with but one exception, between 0·08 and 0·12 second in the first six months. After that period, the P-R interval varied between 0·12 and 0·16 second in the different individuals, in other words, was within the lower normal limits of adult intervals.

Sinus arrhythmia.

The number of children that we were able to examine for sinus arrhythmia (juvenile or respiratory arrhythmia) was thirty-seven. Grouping these according to arbitrary age limits, we have the following table showing the average differences between the longest and the shortest heart cycle at the various ages :

First 24 hours	5 cases	Average difference ·006 second.
First month (Exclusive of the first 24 hours)	7 cases	Average difference ·024 second.
Second to twelfth month	10 cases	Average difference ·032 second.
Second to sixth year	9 cases	Average difference ·040 second.
Seventh to thirteenth year	6 cases	Average difference ·103 second.

Except for the children over seven years of age our figures are, in general, slightly less than those given by Hecht,[2] but agree in the gradual increase in the difference between the shortest and longest heart cycles as the age of the child increases (with the concomitant slowing of the pulse rate).

In our study we have considered a child as showing sinus arrhythmia when the difference between the shortest and longest heart cycles was one-tenth of a second or more. This figure is of course purely arbitrary, but it serves as marking a distinction between those children with slight irregularities of a few hundredths of a second and those with evident arrythmia. The first distinct sinus arrythmia occurred in our series at the age of six weeks (heart cycle difference of 0·12 second). Again at two years we encountered sinus arrhythmia with a heart cycle difference of 0·11 second. After seven years of age the condition became more frequent, and was usually, though not always, of the respiratory type. We have observed a case at seven years with a heart cycle difference of 1·2 seconds ; at eight years with a difference of 1·8 seconds ; at ten years with a difference of 1·0 second, and at eleven years with a difference of 1·7 seconds.

Summary.

Electrocardiograms taken on 42 infants and children varying in age from 1 minute to 12 years show that :—

1. Satisfactory records, containing all the peaks seen in the normal adult electrocardiogram, may be obtained from infants at any period of life.

2. The ventricular complexes associated with preponderance of the right ventricle are constantly found in infants from the time of birth up to the second or third month.

3. The modifications of this phenomenon that occur in the different age periods are produced with remarkable constancy in the individuals of each group. Thus the R peak of lead III ceases to be larger than R^2 between the third and sixth week. In Lead I, the S depression ceases to be greater than the R peak (the other accepted sign of right ventricular

preponderance) between the eighth and ninth week. S^1 continues to be abnormally large, however, in the first two years of life.

4. The initial downward deflection of the ventricular complex, the Q wave, is abnormally large in the infant's electrocardiogram. It is most marked in Lead *III* and from the fourth to the seventh month, but is prominent from the time of birth until the end of our series. The prominent Q^2 and Q^3 should be considered as added signs of right ventricular preponderance ; the big Q^1 of four older subjects as an added sign of left ventricular preponderance.

5. Various abnormalities such as splitting of R and S, inversion or diphasicity of T, are found in the normal infant and child, just as in the normal adult.

6. The T wave, present immediately after birth in the single case that was examined before the cord was cut, became smaller after cutting the umbilical cord, and in all cases was practically absent for the first week. After the first three weeks it reaches a proper size proportionate to the other waves. It is always lowest and frequently inverted in Lead *III*.

7. The actual size of the units of the ventricular complex has varied without any definite relation to the different age periods, but the average size for the young has proved actually greater than the average for adult electrocardiograms.

8. The P-R (P-Q) interval is both actually shorter than the P-R (P-Q) interval of adults and also proportionately shorter where allowance is made for the more rapid heart rate of the infant. It varies from 0·08 to 0·12 second in the first year, and from 0·13 to 0·16 second in the rest of the period of observation.

9. Sinus arrhythmia (to a greater extent than 0.1 second between any of the cardiac cycles of a given record) was not seen before the sixth week and seen only once in the first year. From the sixth year up to the age of puberty (*i.e.* the end of the period of observation) sinus arrhythmia became increasingly more frequent.

We desire to thank Drs. J. C. Gittings, B. C. Hirst, J. P. C. Griffith and A. Ostheimer for assistance and for furnishing material.

BIBLIOGRAPHY.

[1] Funaro (R.) Rivista di Clinica Pediatrica, 1910, viii, 480. This is based on the same work as that used by Funaro and Nicolai (Zentralbl. f. Physiol., 1908, xxii, 58), and O. Heubner (Monatsch. f. Kinderheilk., 1908, vii, 6).

[2] Hecht (A. F.). Ergebn. d. inn. Med. u. Kinderheilk., 1913, xi, 324.

[3] Hoffmann (A.). "Die Elektrokardiographie," p. 69.

[4] Lewis (Thomas). "Clinical Electrocardiography," p. 26.

[5] Lewis (Thomas). Phil. Trans. Royal Soc., London, 1916, ccvii (Ser. B.), p. 288. [B. 340.]

[6] Linetzky (S.). Thesis University of Berlin, 1912.

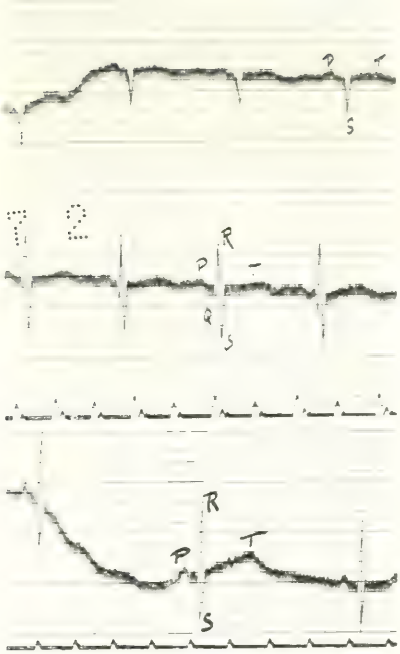


FIG. 2.

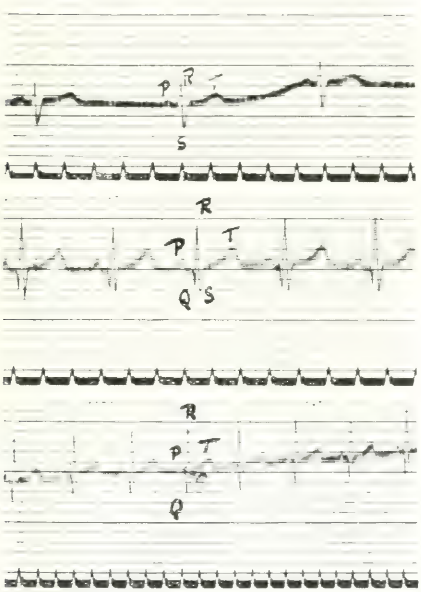


FIG. 3.

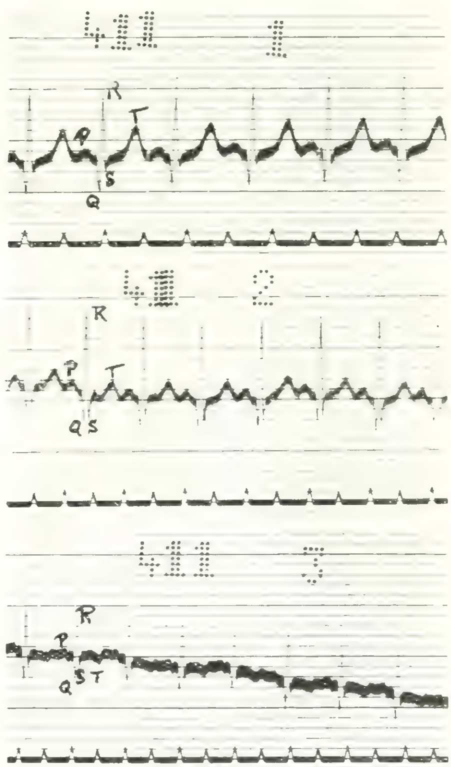


FIG. 4.

Fig. 2. Electrocardiogram from an infant twelve hours old. In Lead I note the absence of R, the depth of S and the small size of T. Note also that R of Lead III is greater than R of Lead II. The Q, R, S complex in this and the succeeding two figures have been redrawn. In all figures the Leads are in their correct order from above down. Ordinates, 5 scale divisions = 1 millivolt. Time in one-fifth sec.

Fig. 3 Electrocardiogram from an infant of six weeks. R^3 is already slightly shorter than R^2, while S^1 is very little bigger than R^1. Note prominence of Q^2 and Q^3, and slight sinus arrhythmia.

Fig. 4. Electrocardiogram from the same infant as in Fig. 2, taken five months later. Except for the prominent Q, this is practically the same as an adult electrocardiogram.

TWO CASES OF BRADYCARDIA IN HORSES. ADAM STOKE'S DISEASE. SINUS-BRADYCARDIA.

By O. BANG, G. PETERSEN and OTTO V. C. E. PETERSEN.

(*From the Veterinary College and Rigshospital, Copenhagen.*)

Bradycardia in horses is, taking it all round, a rather rare disease, apart from its association with staggers. In veterinary writings there appear, however, several reports of abnormally slow pulse in horses, a pulse of 9 even has been observed, while the horse's normal pulse is about 30-40 per minute.

Any unmistakable case of heart-block has, on the contrary, as far as we can see, not been described. Certainly there is a case observed by Lienaux and Hermans (Annales de médecine vétérinaire 1910, page 663) described under the name of : " un cas de pouls lent permanent avec manifestations syncopales chez le cheval," which in all probability was an instance of heart-block, seeing that the pulse was not influenced, at all events, not to any extent worth mentioning, by muscular action (a quarter of an hour's trotting or galloping). No curve of the pulse being shown, and the test with atropin being unsatisfactory seeing that neither the pulse of the sick horse nor those of four healthy horses were influenced by an injection of 0·03 grm. of atropinsulphate, the decisive proof of heart-block is wanting.

We therefore think that the following case of heart-block in horses is of interest, since it is the first fully investigated case. We also give an account of a case of bradycardia in a horse, where the bradycardia temporarily disappeared under the influence of atropin.

1. Case of heart-block. A six year old Russian gelding was brought to the Veterinary School on September the 4th, 1915. It had previously been treated by veterinary H. P. Nielsen, and in his absence by veterinary Plum. It was stated that the horse had belonged to its then owner for a year, also that up to the moment when the horse had been taken ill on the 6th of August, 1915, nothing had been the matter with it. On that day the horse while harnessed to a carriage began to get restive and lay down. The same afternoon veterinary surgeon Nielsen came to look at it ; it was then quiet, but would neither eat, nor drink, and stood dejectedly in the stall. The temperature was 38·4 and the pulse 36. On August the 7th the horse continued to refuse food, the bowels were evacuated frequently ; the temperature was 38·3, and the pulse 20. It was rather lively when taken

out of the stable. On August the 9th the pulse was 36 and regular, the horse lively, feeding well. On August the 12th the pulse was 40 hard but not quite regular. There were no murmurs on examination of heart. On August the 31st the horse was again examined; the pulse was then 12 per minute. On September the 2nd, the horse lively, and behaved as usual. It had gained in flesh since August the 12th; the pulse was 14 and not quite regular. Both sounds of the heart were heard. The owner stated that one day whilst driving the horse it fell down, and that since he has not dared to drive it.

Fig. 1. Curve taken from the neck of the horse with heart block.
a. Auricular contractions. *c.* Ventricular contractions.

On admission to the clinic on September the 4th the temperature was 39·3, pulse 18, and respiration 20. The horse appeared to be languid; the pulse was strong but very irregular; 2 or at the most 3 beats were felt in series, interrupted by long uneven pauses. The beating of the heart was distinctly to be felt on both sides of the chest. The sounds of the heart were somewhat dull, the heart-dulness appeared normal. Distinct pulsation was observed in the jugular veins, the pulse-waves were more frequent in number than the beating of the pulse in the external maxillary artery. The mucous membranes were somewhat cyanotic, there was no œdema. The horse was examined trotting; it was very disinclined to move and after a few minutes would walk no more. The pulse was augmented but very little. On September the 7th a curve of the pulse was taken. At the examination on September the 7th the horse showed slow and irregular action of the heart, long pauses were observed interrupted by 2-3 contractions of the heart in series more rapidly than is normal in horses. During the long pauses no sound was heard, but the neck veins were beating. As it appeared impossible to take any curve from the arteries in the extremities, a curve was taken from the pulsating vein in the neck, and this curve shows heart-block; separated by varying long periods (varying from 3·8 to 7·8 seconds), where the curve only shows insignificant elevations, there appears a group of high peaks (corresponding to the auscultated systoles), which followed quickly after each other. The small elevations during the pause follow each other quite rhythmically and can only be described to auricular contractions. Their frequency is far greater than is normal in horses.

We gave the horse a subcutaneous injection of 5 centigr. of atropin-sulphate, and observed it for half an hour, without the action of its heart being in the slightest degree influenced; on the following day we exercised

the horse. It was put to the trot but responded very reluctantly, and often changed from trotting to walking or stood quite still; there was no change in the action of the heart as a result. During the time the horse was attending the clinic, the pulse rate varied between 12 and 17 as a rule, and was very irregular. On September the 8th at 9 a.m., it was, however, 21, an hour later 39 and almost quite regular. At 12 noon the pulse was again 15, and irregular as usual. The same was the case at 2 and 10 p.m.. The horse, when standing quiet, apparently felt well, but the temperature was somewhat increased, swinging between 38 and 39·2 (normal temperature 37·5), the respirations were normal (about 10). Several times the horse was observed to sway as though dizzy; these attacks soon passed away, however.

On September the 15th the horse suddenly fell down unconscious; this lasted for only a few moments, it rose again and remained in its usual condition until it was killed on September the 16th, 1915.

The diagnosis of heart-block is based on the pulse curves, the atropin test, and the repeated loss of consciousness, and finally, the post-mortem examination.

At the post-mortem examination made by Assistant G. Petersen, it was found that the heart was somewhat enlarged. It weighed 3,160 grms.. The normal weight of a horse's heart is, according to Ellenb. u. Baum's measurement, 2,120-3,440 grms.. The enlargement which only affected the right half of the heart was due to a considerable thickening of the wall of the right ventricle, as well as to dilation of the right auricle. The right ventricle was not dilated. The part of the septum where the left branch of the bundle of "His" divides was apparently more conspicuous than usual.

On the cut surfaces the myocardium appeared to be normal. The semilunar valves as well as the tricuspid valves showed a perfectly normal state.

On microscopical examination an inflammatory infiltration of white blood corpuscles was found in the common branch of the bundle of "His" in the neighbourhood of the division into the two branches.

In the starting point of the left branch a conspicuous infiltration was found, separating the specific muscle fibres. In the consecutive part of this branch small infiltrations were found here and there.

At the spot where the left branch divided into its two chief fasciculi, a very conspicuous infiltration was found which could be followed into the fascicles and continued down round the bundles of the fibres of Purkinje which go down from the left branch into the myocardium. As already stated this part was evidently domed in the fresh heart. In the section of the septum below the division of the left branch some fibres of Purkinje, both just below the endocardium as also down in the myocardium, were found affected, while others had a normal appearance.

Transverse section of the cranial M transversus (trabecula septo marginalis), into which the fasciculus cranialis goes, showed in the neighbourhood of the craniale papillary muscle only a small infiltration with acidophil leucocytes round a single bundle of fibres of Purkinje. A section from the caudal papillary muscle, just where the fasciculus caudalis reaches this latter through M. transversus caudalis, showed two large bundles of fibres of Purkinje with a strong infiltration. Further, all the small bundles found in this section were attacked. In sections of the cranial papillary muscle and also in those of the myocardium below the epicardium only normal looking fibres of Purkinje were found. In the right branch of the bundle of " His " a short distance from the starting point, a weaker infiltration, consisting chiefly of acidophil leucocytes was discovered. A transverse section of the right branch across the middle of the septum showed a small infiltration. The fibres of Purkinje below the endocardium of the septum were normal. Transverse sections of the right branch in M transversus (" Moderator band ") did not show any infiltration. In sections of the marginal papillary muscle in the right ventricle the fibres of Purkinje below the endocardium proved normal, whereas there was a clear infiltration of several bundles of fibres of Purkinje in the myocardium. Sections of the walls of the right ventricle just below the sulcus coronarius showed normal fibres of Purkinje.

The process of inflammation everywhere concentrated upon the connective tissue surrounding the specific fibres. In the caudal papillary muscle in the left ventricle, where, as already stated, the inflammatory infiltration was conspicuous, there was, however, some spread into the surrounding intermuscular connective tissue and into the ordinary muscle fibres of the heart. In the infiltrations appeared beside the ordinary rounded cells (lymphocytes), a number of acidophil leucocytes, which appeared chiefly at the margins of the inflammatory area, generally arranged in long rows in the connective tissue. In several places there were almost exclusively acidophil leucocytes. Where the inflammation was most intense the specific muscle fibres had an atrophic, partly worn out appearance, and were forced away from each other by the lymphocytes, which also entered the fibres themselves. The blood vessels were everywhere congested. The ordinary muscle fibres of the heart everywhere appeared normal. No organisms were showed in sections coloured after Giemsa.

Resumé. Hypertrophy of the wall of the right ventricle. Dilation of the right auricle. The part of the septum where the left branch of the bundle of " His " divides was strongly salient. Microscopically were found sporadic infiltrations in the atrioventricular system of conduction. The chief lesions were in the left branch of the trunk and the caudal papillary muscle. Even affected in smaller degree the common branch and the right branch with the marginal papillary muscle in the right ventricle.

In the septum the fibres of Purkinje from the left branch proved to be partly attacked, while the fibres of Purkinje of the right branch appeared to be normal.

The case presents a picture of acute or sub-acute inflammation of the conducting tissues, similar in its features to those found in man.

CASE 2. The horse, a fifteen-year-old mare, was suddenly taken violently ill with colic, in the night between September the 14th-15th. The owner had possessed the horse for some months, during which time nothing had been the matter with the horse.

On its admission to the clinic at 2.30 a.m., the horse was very restive. The temperature was 38, the pulse 60 and the respiration 32. At the examination in the morning the horse was quiet, looking relatively bright. The mucous membranes were partly cyanotic. The temperature was 37·5, the pulse 40 and the respiration 12. The pulse was very irregular and somewhat weak. 3 and 3 beats of the pulse were felt in series, interrupted by uneven pauses, during which it was thought that weak pulse beats were sometimes felt. The sounds of the heart were clear. Distinct pulsation was observed in the neck-veins.

The horse was made to trot about 400 yards. The pulse then reached 60, being regular. The horse having stood for a little while, the pulse quickly fell and became again arrhythmic. On September the 15th the pulse rate was 28-36, the rhythm being still very irregular. Temperature 37·4. On September the 16th the pulse was 24, irregular, and the temperature 37·5. On September the 17th the pulse was 23 and irregular; the horse was injected with 3 ctgm. atropinsulphate subcutaneously.

9.35 morning	P. 23,	10.03.	P. 36,	10.22.	P. 36
9.45 ,,	P. 29,	10.07.	P. 41,	10.27.	P. 43
9.55 ,,	P. 30,	10.12.	P. 48,	10.35.	P. 44
		10.18.	P. 39,	12	P. 34
				2	P. 30

On September the 18th the pulse was 22 and continuously irregular. After five minutes of trotting the pulse was 65 and regular. The rate fell quickly again. The mucous membranes were constantly cyanotic. The horse walked home. The owner got permission to try the horse on light work. On January the 1st, the owner stated that after its return the horse had worked continually, and had done the same work as the other horses. The driver thought, however, that the horse got tired more quickly than the other horse with which it was working. At the examination the pulse was 24, and irregular. The state of health was just as when the horse was in the clinic.

As a contrast to the preceding case, this horse evidently reacted to atropin, and one may be justified in supposing that the bradycardia was due to an effect of the vagus. Since the horse after four months continued to show pronounced bradycardia there is every reason to suppose that its cause is of a chronic nature, either consisting of an affection of the nervous system or a chronic intoxication.

In order to find out how large a quantity of atropin one must use to produce a considerable rise of pulse rate in normal horses, several horses were subcutaneously injected with from 1-3 centigm. atropinsulphate.

1. Gelding (weight 340 kg.) subcutaneous injection with 2 centigm. atropinsulphate. Pulse before injection, 42 ; after 15 minutes, 48 ; after 30 minutes, 76 ; after 60 minutes, 80 ; after 2 hours, 74 ; and after 3 hours, 60.

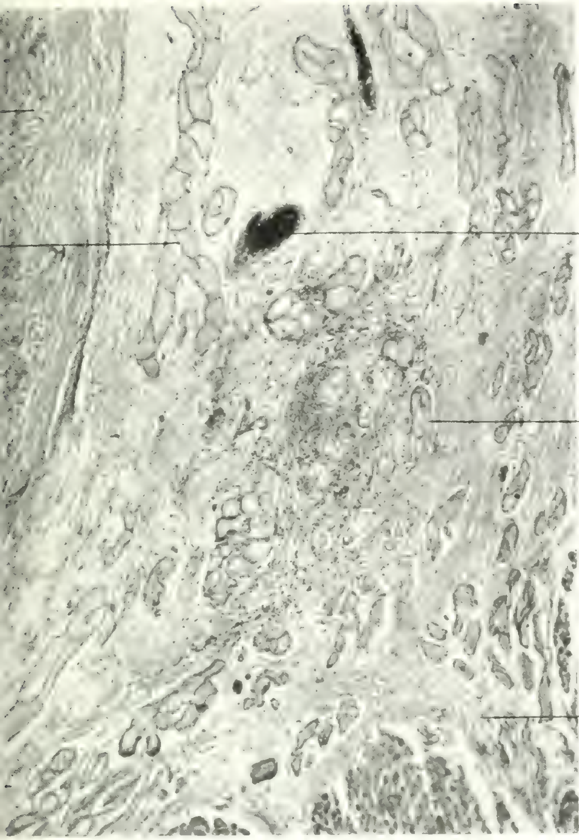
2. Gelding (weight 350-400 kg., the weight was estimated), subcutaneous injection with 3 centigm. atropinsulphate. Pulse before injection, 32 ; after 20 minutes, 75 ; after 40 minutes, 76 ; after 1 hour, 75 ; after 1¼ hour, 77 ; after 2 hours, 72 ; and after 4 hours, 56.

3. Gelding (weight 335 kg.), subcutaneous injection with 1 centigm. atropinsulphate. Pulse before injection, 42 ; after 20 minutes, 52 ; after 40 minutes, 58 ; after 60 minutes, 56 ; and after two hours, 56.

4. Mare (weight 250 kg.), subcutaneous injection with 1 centigm. atropinsulphate. Pulse before injection, 44 ; after 15 minutes, 68 ; after 25 minutes, 76 ; after 45 minutes, 72 ; after 1 hour, 62 ; and after 3 hours, 56.

5. Mare (weight 600 kg.). Pulse 28 intermittent. Subcutaneous injection with 3 centigm. atropinsulphate. After 15 minutes, 39 ; after 25 minutes, 48 ; after 35 minutes, 56 ; after 45 minutes, 54 ; after 1 hour, 56 ; and after 2 hours, 48.

In all the horses strong dilation of the pupil appeared as a consequence of the injection. The reaction is variable in degree (Observations 4 and 5). In small horses doses of atropin of 1-2 centigm. seem to be sufficient to obtain considerable augmentation of pulse rate ; in large horses 3 centigm. suffices, but no doubt one may without danger use larger amounts. The maximum dose for horses is given up to 10 centigm..



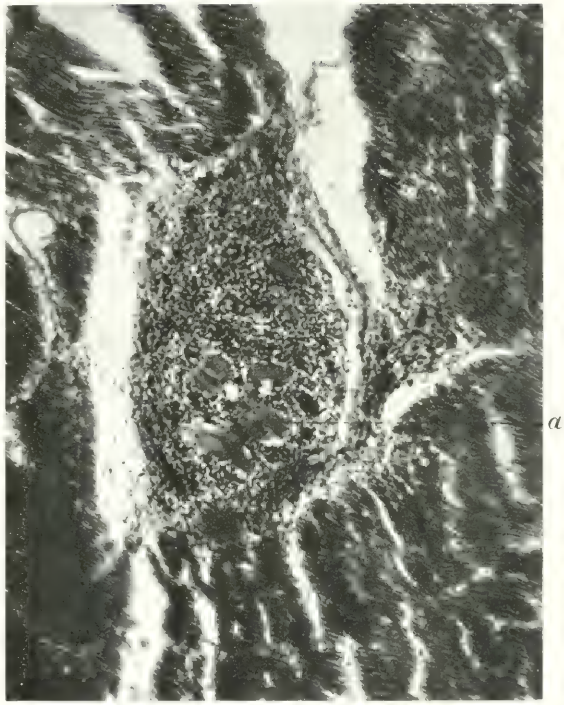


Fig. 2.

Fig. 3.

Fig. 2 Infiltration in of "His" bundle (same horse) near the division of the bundle into its two branches.

a. Septum venticulorum (M. subaorticus).

b. Left branch of "His" bundle.

c. Right branch of "His" bundle.

d. Purkinje's fibres.

e. Blood vessel.

Fig. 3. Infiltration around a bundle of Purkinje's fibres in the hindmost papillary muscle of the left ventricle. *a*. Purkinje's fibres.

THE HEART OF THE SPERM WHALE WITH ESPECIAL REFERENCE TO THE *A-V* CONDUCTION SYSTEM.

By PAUL D. WHITE and WILLIAM J. KERR.

(*From the Medical Service of the Massachusetts General Hospital.*)

In the middle of July, 1915, a young sperm whale 12 feet long was taken in the North Atlantic. Two months later we received the heart which had been well fixed in formalin and was at the time preserved in alcohol (Figs. 1 and 2). When taken from the alcohol its weight was 22 kilograms. Detailed measurements of the heart are given in the table.

TABLE.

	Centimetres.
Length of whole heart	33·0
Breadth of whole heart	56·0
Thickness of whole heart	23·0
Circumference of whole heart	135·0
Inside diameter of aorta at arch	10·0
Diameter of aortic opening	8·5
,, ,, pulmonic opening	11·5
,, ,, mitral ,,	11·0
,, ,, tricuspid	12·0
,, ,, coronary sinus (at mouth)	3·6
,, ,, coronary artery (at mouth)	2·0-2·5
Thickness of left ventricular wall	2·8-6·0
,, ,, right ,, ,,	2·0-4·0
,, ,, interventricular septum	10·0
,, ,, aortic wall	1-2·5*
,, ,, auricular wall	1·8
Width of anterior papillary muscle of left ventricle	8·0

Toward the end of the eighteenth century John Hunter studied the anatomy of several whales, among them a large sperm whale. He wrote as follows regarding the heart of this whale : "Thus the heart and aorta

* Maximum thickness along ridge proximal to attachment of ductus arteriosus.

of the spermaceti whale appeared prodigious, being too large to be contained in a wide tub, the aorta measuring a foot in diameter."[1] Alderson in 1825 described briefly the heart of a sperm whale that was thrown ashore on the coast of Yorkshire. "The diameter of the aorta was $12\frac{1}{6}$ inches; the thickness of the coat of the artery $\frac{7}{16}$ of an inch. Length of the heart, from the apex to the valves of the aorta, 3 feet 10 inches. Near the middle of the left ventricle the wall of the ventricle measured about 5 inches. The diameter of the coronary artery was $1\frac{2}{3}$ inches."[1] In 1885 Turner[3] described the heart of a Sowerby's whale (Mesoplodon Bidens); the heart was flattened dorsiventrally, being $12\frac{1}{2}$ inches broad and 9 inches long. The wall of the right ventricle was $\frac{1}{2}$ to [illegible] inch thick, that of the left ventricle $\frac{1}{2}$ to 1 inch thick. One of the short papillary muscles measured $2\frac{1}{2}$ inches across its base.

The heart of the sperm whale is broad and squat in shape, the ventricles being attached as it were edgewise rather than back to back as in most mammalian hearts. This unusual disposition of the chambers consists of an unusual arrangement of the *A-V* bundle and its branches (Fig. 4). A very large obliterated ductus arteriosus (17 mm. in thickness) is visible in Fig. 2. When the heart was opened there was no sign of free bundle branches and it was only by dissecting beneath the tricuspid valve and excavating the interventricular septum that these structures were found (Fig. 3). The auriculo-nodal junction (*a*) consists of a large band of muscle clearly outlined. The *A-V* node itself (*b*) is wide (1 cm.) but short ($\frac{1}{2}$ to 1 cm.) and has a large nerve trunk (*c*) entering it. The *A-V* bundle (*d*) leaving the node is also short (1 to $1\frac{1}{2}$ cm.) and wide (1 cm.). Both node and bundle have a vertical arrangement instead of the more usual horizontal or oblique position found in other mammalian hearts. Macroscopically the junction of the two structures, node and bundle, is not evident. Firmly attaching the node and bundle to the auriculo-ventricular septum is a broad band of connective tissue (*e*) containing much fat and an artery supplying the node. There is no bone in the auriculo-ventricular groove of the sperm whale as in the ox or sheep heart. Fairly deep in the proximal part of the interventricular septum the bundle divides directly into right and left branches. The right branch is a clear cut cylindrical trunk (3 mm. in diameter) passing down in the papillary muscle of the right ventricle (*f* and *g*). The left branch is a larger broad band of fibres (*h*) (1 cm. broad and 2 to 3 mm. thick) tunnelling through the muscular septum to the left ventricle and its papillary muscles. These branches lie deeply up to their distributing points, from which points smaller branches then approach the endocardium. In no place, however, could a network of Purkinje fibres be seen under the thick endocardium of either ventricle. There were numerous short, thick columnæ carneæ and a few long, delicate trabeculæ crossing the ventricular cavities. In Fig. 3 the tricuspid valve (*i*) is seen rolled back from its attachment and the interior of the right ventricle (*j*) is exposed. The handle

of a wooden mallet may be seen protruding from the mouth of the coronary sinus (*k*).

Microscopically the *A-V* node and bundle and its branches were easily identified. The structure of these was found to be similar to that which has been described for ungulates, especially the sheep, calf and deer.* Keith and Flack[2] did not find marked differentiation between the ordinary ventricular musculature and the fibres of the *A-V* bundle and its branches in the whale which they examined (B. Musculus), but in the sperm whale we have found a very marked difference as seen in Figs. 5 and 6 which are at the same magnification. The node is rich in nerve tissue and ganglion cells. The Purkinje cells of the bundle branches are not long but are very thick, the largest cells measuring 100 micra in diameter. One shown in Fig. 5 measures 140 by 55 micra in cross-section. Purkinje cells seen in sections of the right branch of a red deer's heart and a sheep's heart measured 40 to 70 micra in diameter. A cross-section of the distal part of the right branch (*h* in Fig. 4) is shown in Fig. 5. In this photomicrograph the Purkinje cells are seen in section with large peripheral nuclei and peripheral fibrils. Also the sheaths about the bundle of Purkinje columns are evident. A fair-sized nerve trunk has been found accompanying the Purkinje columns in the bundled branches and in Fig. 5 a nerve branch is seen in section. Fig. 4 shows a photomicrograph of a transverse section of one of the long, delicate trabeculæ crossing the left ventricular cavity close to the apex. It is composed of Purkinje cells supported by connective tissue containing a few small blood vessels and surrounded by the thick endocardium. In sections of one of the columnæ carneæ containing considerable ventricular muscle we have found transitional cells, the terminations of the *A-V* junctional system, uniting Purkinje columns to bundles of ventricular muscle. These transitional cells are intermediate in size and are one-half to three-quarters filled with fibrils; their nuclei also are intermediate in size.

---

* Fully differentiated Purkinje fibres are also present in the heart of the wallaby.

REFERENCES.

[1] Beale (Thomas). "The Natural History of the Sperm Whale." London, 1839.

[2] Keith (A.) and Flack (M.). "The form and nature of the muscular connections between the primary divisions of the vertebrate heart," Journ. Anat. and Physiol., 1907, xli, 172.

[3] Turner (W.). "The anatomy of a second specimen of Sowerby's whale." Journ. Anat. and Physiol., 1885-6, xx. 144.

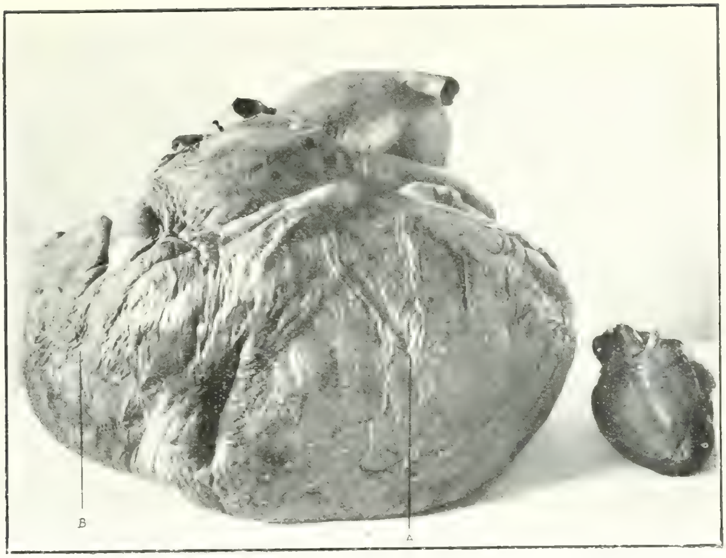


Fig. 1.

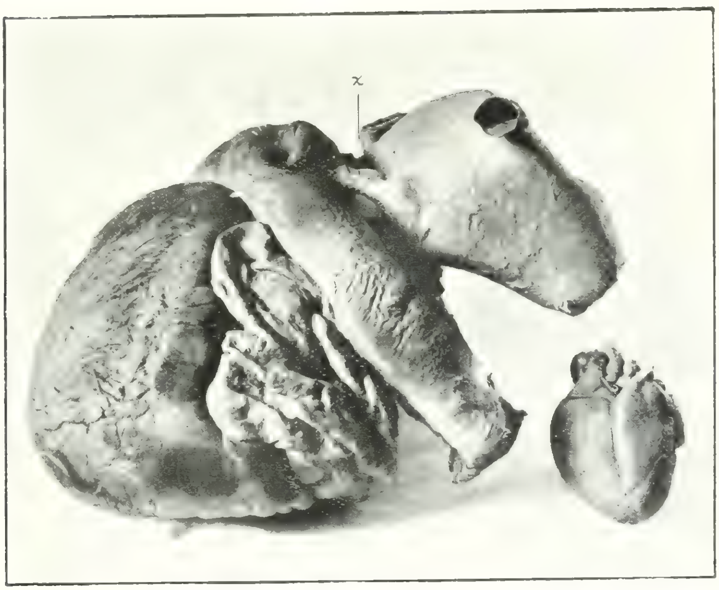


Fig. 2.

Fig. 1. Anterior view of the heart of the sperm whale with large human heart (500 grams) for comparison. *A* left ventricle, *B* right ventricle.

Fig. 2. Side view of the heart showing ductus arteriosus (*x*).

Fig 3

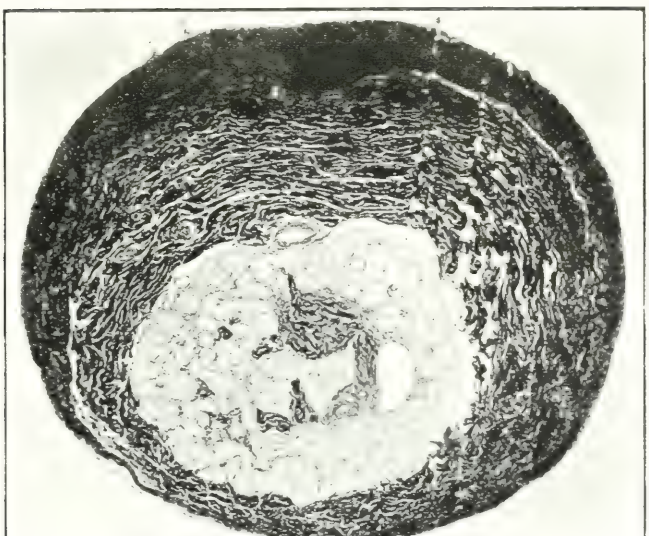


Fig. 4.

Fig. 3. Dissection of the auriculo-ventricular junctional tissues of the heart of the sperm whale.
a—auriculo-nodal junction.
b—*A-V* node.
c—Nerve to *A-V* node.
d—*A-V* bundle.
e—Connective tissue and fat enclosing artery to *A-V* node and bundle.
f-g—Right bundle branch.
h—Left bundle branch.
i—Tricuspid valve.
j—Interior of right ventricle.
k—Mouth of coronary sinus.
l—Coronary artery.

Fig. 4. Photomicrograph of transverse section of trabecula traversing cavity of left ventricle near apex. Magnification—70 diameters.

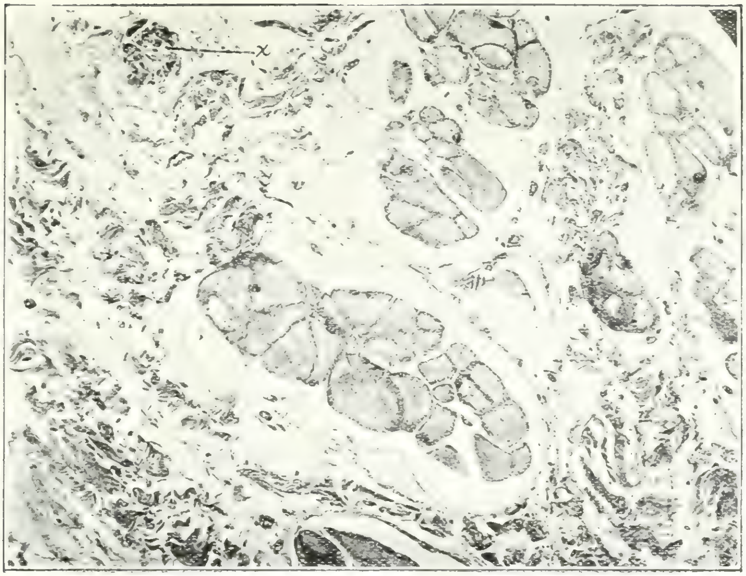


Fig. 5

Fig. 6.

Fig. 5. Photomicrograph of transverse section of right bundle branch of sperm whale (at y in Fig. 4). Magnification—130 diameters. Columns of Purkinje cells in their sheaths are seen. Also a small nerve trunk at x.

Fig. 6. Photomicrograph of transverse section of ventricular muscle of sperm whale. Magnification—130 diameters.

OBSERVATIONS UPON HYPERTROPHY.

By THOMAS F. COTTON.

(*Montreal General Hospital.*)

Much has been written about cardiac hypertrophy and its relation to valvular disease, renal disease, and high blood pressure. It is generally held that the predominance of hypertrophy in the right or left ventricle in valvular disease is dependent upon purely mechanical causes such as valvular defects; that aortic insufficiency leads to hypertrophy of the left ventricle, and that mitral stenosis results in hypertrophy of the right ventricle. It is usual also to associate high blood pressure with hypertrophy of the left ventricle, assuming that the alteration in size of this chamber is brought about by an increase of work put upon it. Such a theory of the causation of hypertrophy in these conditions is based mainly on the physical signs of cardiac enlargement as recorded by the clinician at the bedside, and the observations of the pathologist in the post-mortem room.

It is now recognised that inspection, palpation and percussion indicate in an uncertain fashion the degree of total hypertrophy present in a large heart and that they are especially uncertain indices of preponderant hypertrophy of one ventricle as opposed to the other; and it must be admitted that the routine methods adopted by the pathologists for determining the preponderance of hypertrophy are insufficiently reliable as indices of the relative preponderance of one or other ventricle.

More accurate methods must be applied in investigating cardiac hypertrophy if our knowledge of this condition is to be exact.

Einthoven found in 1906[1] that cardiac hypertrophy is associated with variations in the form of the human electrocardiograms, and stated that hypertrophy in one or the other ventricle can be recognised by these changes in the shape of the electric curve. If this is true much may be learned about hypertrophy and its association with valvular disease and high blood pressure. Lewis, in testing the statement of Einthoven, observed that some electrocardiograms were out of harmony with the usual physical signs of right and left hypertrophy; that in aortic insufficiency, where he expected a left preponderance, the electrocardiogram showed no preponderance or a right preponderance, and that the heart of renal disease could have right, left or no preponderance. He had noted, however, that right

218 T. F. COTTON.

TABLE I. MITRAL STENOSIS.

No.	Case No.	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S.	L./R.	Mitral Valves.	Other valve defects.	Coronary Arts.	Kidneys.	Sys. B.P.	Remarks.
1	195	12 M		176	56·0	92.0	28·0	1·64	Stenosis regurgitation.	Nil	Nil		82	Syphilitic.
2	189	42 M		269·0	120·2	99·4	49·4	·82	Button-hole regurgitation.	Nil	Nil	Chronic nephritis		Pericarditis. Thrombosis left auricle. Auricular fibrillation.
3	236	20 F		201·9	68·0	89·0	44·9	1·30	Stenosis	Aortic regurgitation	Nil	Chronic nephritis	115	
Average	..	..		215·6	81·4	93·5	40·8	1·25						

TABLE II. AORTIC DISEASE.

No.	Case No.	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S.	R./L.	Aortic Valves.	Other valve defects.	Coronary Arts.	Kidneys.	Sys. B.P.	Remarks.
1	105	40 M		532·0	71·0	349·0	112·0	4·91	Regurgitation	Mitral regurgitation	Nil	Nil	130	Lesion rt. branch *A-V* bundle.
2	142		40 M	495·4	139·2	272·0	84·2	1·95	Regurgitation	Mitral regurgitation	Nil	Nil	110	Syphilitic hemiplegia.
Average	..	..		513·7	105·1	310·5	98·1	3·43						

preponderance was constant in pulmonary stenosis, and that the electrocardiogram of the infant gave the signs of right preponderance within the first three months of life, the signs disappearing later.

He was led from these observations separately to weigh the ventricles of a large series of hearts, and to compare these weights with the usual physical signs of cardiac enlargement, and also where possible with the special electrocardiographic signs.[1] To obtain the separate weights of the ventricles he used a technique similar to Muller's, which enabled him to isolate the muscle of these two chambers to compare their weights, thus determining in a more exact manner the actual and relative hypertrophy. This method he has fully described so that it is unnecessary for me to do so in detail.[2] I dissected many of the hearts of his series, and later at the Montreal General Hospital used the same method of dissection to obtain the separate ventricular weights of 51 hearts of a new series in cases which I had observed during life.

It is not my purpose to compare the physical signs in these cases with the relative ventricular weights. This comparison Lewis has made and has shown that there is great variation between those signs commonly employed to denote hypertrophy of the left or right ventricle, and the relative hypertrophy in these chambers. He is of opinion that the electrocardiographic signs are the most reliable which we possess in estimating preponderance clinically. My observations in general confirm his ; I find that increase in cardiac dulness to the left does not necessarily indicate a predominance of hypertrophy in the left ventricle ; and that great increase in the size of the right chamber may be present without any sign of epigastric pulsation or epigastric thrust.

In six cases where I obtained electrocardiograms before the ventricular weights were taken, I found that preponderance of hypertrophy in one or other chamber was confirmed by the relative ventricular weights in four. Lewis in a large number of cases measured the heights of the waves in the electrocardiograms, and comparing them with the relative ventricular weights obtained results which enabled him to confirm the statement of Einthoven that certain forms of the electrocardiograms could be associated with hypertrophy of the right or left ventricle. He also constructed tables comparing the relative ventricular weights in cases of mitral stenosis, aortic insufficiency, and renal disease with high blood pressure. He found that the average values in mitral stenosis gave a greater increase in weight of the right ventricle than the left ; that in aortic disease preponderance of hypertrophy in the left chamber was not constant, and that in renal disease general enlargement was the rule. Further collected observations seem desirable and the present tables are published with the purpose of swelling the figures.

Table III. Interstitial nephritis (contracted kidney).

No.	Case No.	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S	L./R.	Valve Defects.	Kidneys.	Sys. B.P.	Remarks.
1	73	33 F		310·0	70·0	167·0	73·0	2·38	Mitral regurg.		192	Alb. retinitis urea in blood, 1·23 gms. per litre.
2	147	41 M	720·0	404·0	83·5	220·0	100·5	2·63	Mitral regurg.	Wgt. 370 gms.	240	Chr. pericarditis. Pulm. tbc. Cirrhosis of liver.
3	59	59 F	330·0	146·4	39·9	75·7	30·8	1·90	Nil	Wgt. 230 gms.	215	Thickening mitral and aortic valves. Hemiplegia.
4	5	47 M		342·1	63·5	211·5	67·1	3·33	Nil		220	
5	47	38 M	400·0	179·0	53·0	95·0	31·0	1·79	Nil	Wgt. 180 gms.		Lateral sinus thrombosis.
6	265	66 M		421·1	98·8	252·0	70·3	2·55	Nil		150	
7	197	35 F	380·0	250·1	67·7	120·1	62·3	1·76	Nil	Wgt. 120 gms.	210	Sclerosis aortic cusps pericarditis.
8	185	41 M		527·7	184·2	271·5	72·0	1·47	Nil	Wgt. 100 gms.	238	
9	33	65 F	450·0	184·9	54·5	94·5	35·9	1·73	Nil		180	Auricular fibrillation. Cerebral hæmorrhage.
10	11	64 M		274·3	54·5	152·3	67·5	2·79	Nil		190	Auricular fibrillation. Cerebral hæmorrhage.
11	40	56 M	620·0	306·1	99·5	162·2	44·4	1·63	Nil	Wgt. 175 gms. Red granular	130	Myocarditis.

TABLE III—*continued.*

No	Case No.	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S.	L./R.	Valve Defects.	Myocardium.	Kidney.	Sys. B.P.	Remarks.
12	101	50 M		350·5	93·5	184·0	73·0	1·97	Nil	Myocarditis Coronaries nil	Chr. Nephritis	118	
13	52	64 F	320·0	155·0	50·0	85·2	19·8	1·70	Nil	Aortic scleroris	Chr. Nephritis		Septic broncho pneumonia.
14	78	40 M	430·0	249·0	99·5	109·5	40·0	1·10	Nil	Myocarditis	Chr. passive congestion	190	Extensive fibrosis of lungs.
15	258	46 M		404·3	99·5	241·0	63·8	2·42	Mitral regurg.		Granular kidney		Uraemia.
16	225	58 M	600·0	333·7	99·5	154·2	80·0	1·55	Mitral regurg.		Granular kidney	150	Arterio-sclerosis auricular fibrillation.
17	12	40 F	300·0	138·5	30·0	76·5	32·0	2·55	Nil	Myocarditis	Granular kidney		
Average		. .	455·0	292·7	78·9	157·2	56·7	2·07					

TABLE IV. INTERSTITIAL NEPHRITIS (LESS DEFINED).

No.	Case No	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S.	L./R.	Valve Defects.	Kidneys.	Sys. B.P.	Remarks.
1	109	68 M		174·1	54·6	86·5	33·0	1·58	Nil	380 gms.	105	Hemiplegia.
2	48	70 M	480·0	240·0	65·2	132·3	42·5	2·02	Nil	480 gms. Swollen congested.		General arterio-sclerosis.
3	36	48 M	480·0	242·0	67·0	135·2	39·8	2·01	Nil	Pyelitis. Wgt. 330 Chr. Nephritis	180	Myocarditis. Uraemia.
4	167	45 M	350·0	108·9	29·2	60·7	19·0	2·08	Nil			Diabetes, pleuritis.
Average		. .	436·6	191·2	54·0	103·7	33·6	1·92				

In a series of 13 controls (Table No. VII) I found the relative weights of the two chambers ($\frac{L}{R}$) to be 1·82, a slightly higher value than that given by Lewis (1·79). My cases of mitral stenosis (Table No. 1) are three with an average total ventricular weight of 215 grammes, and the index for the left ventricular weight divided by the right ventricular weight ($\frac{L}{R}$) of 1·25. This index $\frac{L}{R}$ standing at 1·25 speaks for a definite right preponderance. Lewis's value 1·55 is higher because he includes a number of cases in which the degree of stenosis was slight. The average of our combined results (Table VIII), including 19 cases of pure mitral stenosis, has a value for $\frac{L}{R}$ of 1·50, and for the ventricular weight 250 grammes. It can therefore definitely be stated that in unselected cases of mitral stenosis there is in the average a general enlargement of the heart with preponderance of the right ventricle.

In two cases of aortic disease the average ventricular weight was 513·7 grammes, and the relative ventricular weight of the two ventricles 3·43. In one of these with great enlargement of the whole heart, the index was 1·95, in the other great hypertrophy of the left ventricle was outstanding, the index being 4·91. Our combined weights give an average index of 2·32 for 15 cases, a value slightly higher than Lewis's average of 2·15 (13 cases). Left preponderance is hardly the rule in pure aortic disease, seeing that it was found in only 8 out of 15 cases while the hypertrophy though massive was equally distributed in the two chambers or the right ventricle preponderated in 7 instances.

In a group of 17 cases of interstitial nephritis of the form known as granular contracted kidneys (Table No. III) the average total ventricular weight was 292·7 grammes, the index $\frac{L}{R}$ was 2·07. Lewis tabulates 10 cases ; the combined series yields an index of 1·99, showing slight but clear preponderance of the left chamber. But in Table III in several cases, while there is great enlargement of the heart, the hypertrophy is equally distributed throughout both chambers, and neither is preponderant, and in four cases there is actual preponderance of the right chamber. The preponderance of the left chamber in my series occurs in 8 out of 17 cases ; in the combined series in 13 out of 27 cases. Preponderance of the left ventricle in granular kidney is therefore no more the rule than the exception, though the index is raised somewhat in the average. In four cases the nephritis was of less defined type (Table IV) ; in two of these there was ventricular enlargement, in two there was none ; in three there was a preponderance of the left ventricle.

Taking all cases of renal disease and selecting those with high blood pressure for comparison with the remainder, the influence of blood pressure upon hypertrophy is scarcely to be shown. The index $\frac{L}{R}$ in all renal cases in my series is 2·04 ; in the combined series of 48 cases it is 2·00 ; 13 of these showed a blood pressure of 180 or more and in these the index is increased to 2·06.

TABLE V. MYOCARDITIS.

No.	Case No.	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S.	L./R.	Valve Defects.	Myocardium.	Kidneys.	Sys. B.P.	Remarks.
1	46	27 M		143·8	42·1	70·7	31·0	1·67		Coronaries nil			Syphilis. Auricular fibrillation.
2	234			447·2	92·7	265·0	89·5	2·86					Auricular fibrillation.
3	15	13 M	250	121·2	36·2	65·2	19·8	1·80	Nil	Myocarditis Coronaries nil			Heart-block.
4	39	40 M	380	158·9	49·0	72·7	37·2	1·48		Myocarditis Coronaries nil	Nil		Syphilis. Heart-block.
5	176	54 F		267·2	81·8	153·7	31·7	1·88	Mitral regurg.			175	Auricular fibrillation.
6	224	27 M		190·5	44·0	113·5	33·0	2·58	Nil		Albumin gran. casts		
7	190	27 M	600	302·9	79·3	173·8	49·8	2·19	Mitral regurg.	Myocarditis			Chr. endocarditis. Mitral and aortic valves.
Average . .			410	233·1	60·7	130·6	41·7	2·06					

TABLE VI. UNCLASSIFIED.

No.	Case No.	Age and Sex.	Heart weight in gms.	Vent.	R.	L.	S.	L./R.	Valve Defects.	Myocardium.	Kidneys.	Remarks.
1	213	34 M		275·5	75·0	146·5	54·0	1·95	Acute mitral and aortic endocarditis	Nil	Nil	
2	96	42 M	400·0	204·0	56·0	120·0	28·0	2·14	Nil	Myocarditis	Chr. pass. congestion	Pericarditis with effusion broncho pneumonia.
3	166	26 M		139·5	44·0	75·5	20·0	1·71	Nil	Nil	Nil	Acute pericarditis. Typhoid fever.
4	169	62 M		176·1	51·7	101·7	22·7	1·96	Nil	Nil	Nil	Chr. pericarditis. Acute lobar pneumonia.
5	3	30 F	250·0	188·7	54·7	93·4	40·6	1·70	Calcification aortic cusps	Nil	Acute nephritis Wgt. 300 gms	Acute lobar pneumonia.

Table VII. Controls.

No.	Case No.	Age and Sex.	Disease.	Heart weight in gms.	Vent.	R.	L.	S.	L./R.	Remarks.
1	171	$2\frac{3}{12}$ M	Stricture of oesophagus		20·0	5·2	11·1	3·75	2·13	
2	186	23 M	Typhoid perforation		259·0	64·7	148·0	46·3	2·28	Atheromatous coron
3	180	28 M	Addison's disease	230	175·9	54·7	97·1	24·1	1·77	Atheroma of aorta.
4	189	53 F	Cerebral tumour Broncho pneumonia		145·5	45·3	85·3	14·9	1·88	Myocardium fatty.
5	202	71 M	Carcinoma of gall bladder		107·8	34·1	53·0	20·7	1·55	
6	143	26 F	Acute appendicitis		192·6	54·3	96·8	41·5	1·78	
7	144	60 M	Acute lobar pneumonia		155·5	44·7	86·8	24·0	1·94	
8	14	53 M	Cirrhosis of liver	300	146·1	40·6	77·2	28·3	1·90	
9	142	36 F	General peritonitis	300	160·8	50·6	84·2	26·0	1·65	Broncho pneumonia
10	206	48 hrs. M	Pneumonia		33·5	4·5	5·8	22·0	1·29	
11	30	64 M	Appendicitis		163·3	43·0	94·8	25·5	2·20	
12	31	22 M	Cerebral concussion	350	221·5	74·8	107·7	39·0	1·43	
13	41	69 M	Strangulated inguinal hernia	420	208·9	60·0	111·0	37·9	1·85	
			Average	320	153·8	44·3	81·4	27·2	1·82	

Table VIII. Table of combined averages.

Disease.	No. of Cases.	Heart weight.	Vent.	R.	L.	S.	L/R
Mitral stenosis	19		250·2	94·8	113·3	42·1	1·50
Aortic disease	15	713 (13)	433·9	111·7	250·8	71·5	2·32
Interstitial nephritis (advanced)	27	485·0	289·9	80·9	156·2	52·9	1·99
Twelve of these cases with B.P. of 180 or more	13	487·7	295·3	80·3	157·9	57·2	2·06
Interstitial nephritis (less defined)	13	522	276·5	82·2	150·1	44·2	1·91
All renal cases	48	506	296·7	83·5	162·6	50·6	2·0
All patients with B.P. of 180 or more	25	545	309·7	80·8	173·6	55·2	2·22
Controls	25	295 (15)	154·5	45·4	81·9	27·1	1·80
Myocarditis	7	410	233·1	60·7	130·6	41·7	2·06

TABLE IX. ELECTROCARDIOGRAMS (IN MILLIVOLTS) AND MUSCLE WEIGHTS (IN GRAMMES) COMPARED.

No.	Case No.	Lead I.					Lead II.					Lead III.					Heart wgt.	Vent. weight.	R.	L.	S.	L./R.	Disease.
		P.	Q.	R.	S.	T.	P.	Q	R.	S.	T.	P.	Q.	R.	S.	T.							
1	189	0	0	1	6	·5	0	0	4	4	1	0	0	4·5	3·5	1		269	120·2	99·4	49·4	0·82	Mitral stenosis.
2	236	1·5	2	1·5	·5	1·5	2·5	0	5	0	4	1	0	4·5	0	4·0		201·9	68·0	89·0	44·9	1·30	Mitral stenosis.
3	147	1·5	1·0	16·5	1	·5	1·5	0	6	0	2	1	0	1·5	15·5	2	720	404·0	83·5	220·0	100·5	2·63	Renal disease.
4	265	1	1	4	0	2	1	0	1·5	10	1	1	0	1·5	15	2		421·1	98·8	252·0	70·3	2·55	Renal disease.
5	101	1	0	2·5	2	1	2	1·5	13	0	2	1	2	10·5	0	1		350·5	93·5	184·0	73·0	1·97	Renal disease.
6	225	1	1	7	2	1		0	4·5	4	1		0	1	5	1	600	333·0	99·5	154·2	80·0	1·55	Renal disease.

I have included a table of 7 cases (Table V) under the term Myocarditis. In these seven cases there is a considerable increase in weight of the ventricles, in four, and the preponderance of hypertrophy is in the left ventricle. But the variation in the values from case to case is so variable that I hesitate to draw any conclusions.

There are five cases which I have not classified (Table VI). Three of these died of acute endocarditis and pericarditis, one other of chronic pericarditis, and one of acute nephritis. The cases of endocarditis and pericarditis with effusion showed hypertrophy and the indices were 1·95 and 2·14. The cases of acute pericarditis and acute lobar pneumonia complicated by acute nephritis gave normal $\frac{L}{R}$ values. The remaining case of chronic pericarditis the $\frac{L}{R}$ ratio was 1·96.

In Table IX I give the measurement of the different deflections in six electrocardiograms and have compared these measurements with the relative ventricular weights. In two cases of mitral stenosis (Nos. 1 and 2) the electrocardiograms show right preponderance and the ventricular weights give a low $\frac{L}{R}$ ratio; two cases of renal disease (Nos. 3 and 4) with left preponderance have a correspondingly high $\frac{L}{R}$ ratio.

In *CASE* 5 the curves tend to show right preponderance, while the index is practically normal. The discrepancy is greater in *CASE* 6, where with curves of left preponderance the index is as low as 1·55 (preponderance of right ventricle). It should be remembered that the electrocardiograms from the patients used in the observations are taken several or many weeks before death, and that considerable alterations of the electrocardiograms during the terminal period of life are not unknown. In the light of previous observations I am compelled to regard *CASE* 5 as exceptional. The explanation of the discrepancy is possibly to be found in progress of the hypertrophy during the last few weeks of life (Table IX).

REFERENCES.

[1] EINTHOVEN. Archives internat. de physiol., 1906-7, IV., 132.

[2] LEWIS. "Heart," 1913-14, V., 367.

OBSERVATIONS UPON DERMATOGRAPHISM WITH SPECIAL REFERENCE TO THE CONTRACTILE POWER OF CAPILLARIES.*

By THOMAS F. COTTON, J. G. SLADE, and THOMAS LEWIS.

Types of Tache.

If a blunt point is drawn firmly over the skin in the interscapular region, the reaction of this stimulus is varied in different subjects. The reaction varies both in its nature and in its degree.

We have studied it in a large number of soldiers who suffered from the condition known as irritable heart ; in this affection the reaction is almost always conspicuous.

Red and white tache. (Fig. 1 *a.*) In its usual form the tâche consists of a uniform red flush, accurately following the line of pressure and having sharply defined margins each bordered by a distinct area of pallor. We shall refer to this form of tâche, a line of vasodilation bordered by lines of vasoconstriction as the red and white tâche : the lines themselves will be termed the red line or the white line of the tâche.

Simple tache. (Fig. 1 *b.*) The least common variety of reaction is a simple red line, the white line being absent. On some skins faint white lines appear to border this simple red line, but in the case of a simple tâche this appearance is an illusion, for if the red line is concealed by placing the edge of a sheet of paper over it, the white line also disappears. If a red yellow wash of the colour of skin is painted on a sheet of paper and a deep red line is painted upon this background, paler areas often seem to border the red line.

Spreading tache. (Fig. 1 *c.*) Another form of reaction is a red line, in which after a short while the sharp definition of the margin is partially lost ; the immediately surrounding area of the skin becomes hyperæmic, though

* These observations were carried out at the instance of the Royal Medical Research Committee ; they were undertaken at the Military Hospital, Hampstead.

the suffusion is irregular or blotchy. A similar outlying flush is frequently witnessed in instances of red and white tâche (Fig. 1 *d*) and affects the skin bordering the white line ; yet it does not invade the white line.

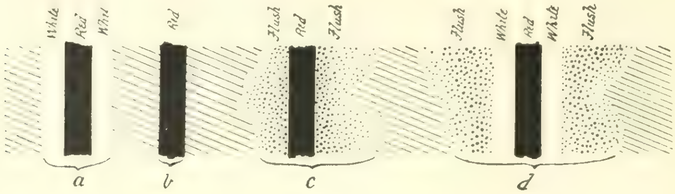


FIG. 1.

These tâches are illustrated diagrammatically in Fig. 1. The relative frequency of the types in 84 patients has been as follows :—

TABLE I.

Red and White	vivid or spreading	30	
	moderate	19	53
	slight	4	
Simple	vivid	4	
	moderate	6	12
	slight	2	
Spreading	vivid	19	19
			84

The tâche varies a good deal in conspicuousness, being brilliant in its colouring in more than half the patients ; the spreading tâche is almost always vivid ; when the red line of a red and white tâche is vivid, so is the white line, but the most vivid red lines are simple or have a border of red flush. In about half the patients the red line ultimately becomes palpable ; in 25% a visible urticaria developes ; and in 5% a fully developed wheal is seen.

Distribution. While most of our observations have been made upon the interscapular region, we find that a tâche is obtainable over almost the whole surface of the body.* The tâche varies in brilliancy in different regions ; it is most conspicuous on the back of the thorax, especially between the scapulae ; [1 & 6] it is almost as conspicuous over the front of the chest and

* The palms of the hands, soles of the feet and face and scalp have not been tested.

abdomen ; in other regions it is usually less conspicuous. Its form and time relations vary in different regions but not uniformly from subject to subject. (Table III.)

The onset of the visible reaction is relatively slow upon the extremities, though exceptions to this rule are noted. In the skin of the forearm it often happens that a white line is alone developed even with relatively heavy pressure ; over the thigh on the contrary a red reaction may alone be seen. The full time relations of the regional reactions are given in the accompanying tables.

TABLE II.

Daily and Weekly Tache Chart.

Name.	Heavy Stroke.						Light Stroke.	Date.
	Vivid.			Moderate.		Slight		
	Urticarial.	Spreading.	Red and White.	Spreading.	Red and White.	Red and White.	White Line.	
Guest					+		viv.	12/3/16
					+		viv.	13/3/16
			+				viv.	14/3/16
					+		viv.	15/3/16
					+		viv.	25/3/16
	+	+	+				viv.	26/3/16
	+	+	+				viv.	1/4/16
	+	+	+				viv.	8/4/16
Butcher		+					0	12/3/16
		+					0	13/3/16
		+					0	14/3/16
		+					0	15/3/16
		+					Red sl.	16/3/16
		+					0	25/3/16
			+				Red	1/4/16
Spencer					+		viv.	12/3/16
			+				viv.	13/3/16
			+				viv.	14/3/16
			+				viv.	15/3/16
			+				viv.	16/3/16
					+		viv.	25/3/16
			+				viv.	1/4/16
			+				viv.	8/4/16
Brooks					+		+	12/3/16
				+			sl.	13/3/16
				sl.	+		0	14/3/16
				sl.	+		sl.	15/3/16
	Spre	ading	with	sl.	+		sl.	16/3/16
	heavi	er pre	ssure.	sl.	+		0	25/3/16
				sl.	+		sl.	1/4/16
				sl.	+		sl.	8/4/16
Bennett					+		viv.	12/3/16
				+			sl.	13/3/16
						+	+	14/3/16
						+	+	15/3/16
	Spre	ading	with			+	+	16/3/16
	heavi	er pre	ssure.		+		viv.	25/3/16
						+	viv.	1/4/16
				+	+		+	8/4/16

TABLE II.—DAILY AND WEEKLY TACHE CHART—*continued.*

NAME.	HEAVY STROKE.						LIGHT STROKE.	DATE.
	VIVID.			MODERATE.		SLIGHT.		
	Urticarial	Spreading.	Red and White.	Spreading.	Red and White.	Red and White.	White Line.	
KICKEVITZ				+	+		+	12/3/16
					+		+	13/3/16
					+		+	14/3/16
					+		+	15/3/16
					+		+	16/3/16
					+		+	25/3/16
					+		+	1/4/16
				+	+		+	8/4/16
TETLEY			+				0	12/3/16
			+				0	13/3/16
			+				0	14/3/16
		sl.	+				sl. red	15/3/16
		sl.	+				sl. red	16/3/16
		sl.					sl.	25/3/16
		+	+				sl.	1/4/16
			+				sl.	8/4/16
CHILDS						+	+	12/3/16
						+	+	13/3/16
						+	sl.	14/3/16
						+	sl.	15/3/16
						+	sl.	16/3/16
					+		sl.	25/3/16
						+	sl.	1/4/16
						+	sl.	8/4/16
ROBERTS			+				+	12/3/16
			sl.				+	13/3/16
			+				sl.	14/3/16
			+				sl red	15/3/16
			+				sl.	16/3/16
								25/3/16
	+	sl.					sl.	26/3/16
DONOLLY			+				+	12/3/16
			+				viv.	13/3/16
		+					sl.	14/3/16
		+					sl.	15/3/16
		+					sl.	16/3/16
		+	+				sl.	25/3/16
		+	+				sl.	1/4/16

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			0.3												[illegible]	[illegible]
[illegible]						0.35				[illegible]						
[illegible]											1.58					
Rt [illegible]																
[illegible]									20	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]									[illegible]	[illegible]			[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]								[illegible]			[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]			1.10 mod	[illegible]		[illegible]	1.42			2.28	7.50	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]										2.50	4.0		
[illegible]	[illegible]		[illegible]				[illegible]			1.8	[illegible]		2.7	2.0	2.?	
[illegible] Back	[illegible]		[illegible]	0.20	[illegible]		[illegible]		2.4		1.25	1.12	1.5			
Chest	[illegible]		0.14	0.32	1.12 mod.		1.42 mod	mod	1.22		1.50		[illegible]		7.0	[illegible]
Abdomen	[illegible]	[illegible]	0.14	[illegible]	[illegible]	[illegible]	[illegible]	0.40 sl	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	.20
Rt arm flex	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Rt arm ext	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Rt forearm flex	[illegible]		[illegible]	[illegible]	[illegible]		[illegible] mod	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Rt forearm ext		0.26	[illegible]	0.26	[illegible]	[illegible]	0.50 mod.	0.40 sl	[illegible]	[illegible]	[illegible]	2.50	[illegible]	.40	.40	[illegible]
Rt thigh outer surf	0.20	1.24	[illegible]	0.50	0.20	1.5 mod.	[illegible] sl	[illegible] sl		1.45	[illegible]	1.00	1.10	[illegible]	5.10	3.10
Lt thigh inner surf	0.15	1.15	0.20		1.32 mod	1.18 mod	1.22 v.v.	[illegible] sl	[illegible]	1.15	[illegible]		2.20	1.35	3.50	3.30
Rt leg outer surf	0.20	1.22	0.24		[illegible] v.v.	0.35 v.v.	1.10 v.v.	0.50 sl	1.50	[illegible]	1.50	1.50	6.50	[illegible]	6.30	[illegible]
Lt leg inner surf	[illegible]		0.48		[illegible] sl		1.30 sl		[illegible]		[illegible]		3.50		5.30	
[illegible] Back	0.8	0.22	0.16	0.32	[illegible]	[illegible]	1.5 mod	1.0 sl		[illegible]	1.10	1.27	8.0		7.5	[illegible]
Chest	[illegible]		[illegible]	0.32	[illegible]		1.32 sl	1.42 sl	[illegible]		[illegible]	1.58	[illegible]		[illegible]	1.5
Abdomen	[illegible]	[illegible]	0.10		[illegible] mod	[illegible] sl	[illegible] sl		2.5		[illegible]		[illegible]	[illegible]	5.30	
Rt forearm flex	0.22	0.22	[illegible]	0.22	[illegible] sl	0.40 sl	[illegible] v.v.	[illegible] v.v.	1.10		2.40	1.40	[illegible]		[illegible]	1.20
Rt arm flex	0.20		0.20	0.42	[illegible] mod		0.50 mod.	1.5 sl			[illegible]	[illegible]			[illegible]	2.5
Rt arm ext	[illegible]	[illegible]	0.15	[illegible]	[illegible]	1.20	1.0 sl	0.15	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.10	3.5
Rt thigh outer surf	0.20	0.22	abs		1.12	2.0			2.40				7.0	[illegible]		
Lt thigh inner surf	[illegible]	[illegible]	abs		1.0	0.40 v.v.			[illegible]	1.12			2.10	.25		
Rt leg outer surf	0.26	0.26	abs		0.50 sl	2.0 v.v.			1.16	2.40			2.40	2.49		
Lt leg inner surf	0.30	0.30			2.0 sl	2.5 mod	1.50 sl						2.25	2.30	2.25	
[illegible] Face	[illegible]	0.22	1.15	[illegible]	[illegible] v.v.	[illegible]	[illegible]		1.40			1.45	18.0		7.0	5.23
Chest	0.28	[illegible]	0.12	0.45	Palp.		0.45	1.40	1.40		1.22		11.0		6.23	3.11
Rt arm flex	0.40	[illegible]	0.38	[illegible]	[illegible] palp.	1.20	[illegible]	1.20	[illegible]		2.30	2.40	10.0		[illegible]	10.8
Rt arm ext	.42	0.28	0.38	2.10	[illegible] sl	1.10 v.v.	1.25 mod		[illegible]	[illegible]				[illegible]	.50	
Rt forearm flex		1.35	0.40	0.40			[illegible]	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]
Rt forearm ext		1.45	[illegible]	[illegible]			[illegible] sl	[illegible] sl								
Rt thigh outer surf	[illegible]	0.11	0.42	0.42	1.45 mod	0.34	[illegible]	[illegible] mod		[illegible]		1.46	5.10	[illegible]		3.45
Lt thigh inner surf	[illegible]	0.20		1.8	1.15	1.18			1.30	1.34			2.25		2.40	2.40
Rt leg outer surf	0.28	0.20	0.42		1.20	[illegible]			1.26				2.30	5.45		
Lt leg inner surf	1.42	0.28		[illegible]	[illegible]	[illegible]	[illegible]	[illegible] mod	2.20		2.30		1.18			3.52
[illegible] Back	[illegible]	0.22	[illegible]	1.2 sl	2.32 [illegible]	2.20 mod	2.42 mod	2.15 v.v.	3.25	[illegible]	[illegible]	3.12	[illegible]	4.55	5.55	
Chest	.18	0.20	0.22	[illegible]		.20	2.40 [illegible]		2.45	2.55		[illegible]	8.0		6.0	8.0
Abdomen	0.20	[illegible]	1.12	1.22	[illegible] palp	[illegible] mod	[illegible]	2.25		[illegible]		[illegible]	[illegible]		[illegible]	[illegible]
Rt arm flex	[illegible]	[illegible]	0.25	[illegible]			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Rt arm ext	[illegible]	[illegible]	[illegible]	0.50	1.2 palp. v.v.	[illegible]	2.2 v.v.	2.2 v.v.		1.25	[illegible]	3.10	9.0		6.0	5.45
Rt forearm flex	.18	0.24	0.42	[illegible]	[illegible]	1.5	2.25 mod	2.12		[illegible]		[illegible]	11.0		8.0	11.0
Rt forearm ext	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.12	2.12		2.50	[illegible]	3.10	[illegible]		7.51	7.30
Rt thigh outer surf	1.12	[illegible]	[illegible]	[illegible]	[illegible]	0.50	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Lt thigh inner surf	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.42		[illegible]				3.10	[illegible]			[illegible]
Rt leg outer surf	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]				[illegible]	11.0		[illegible]	[illegible]
[illegible] Back	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			1.43	1.32		7.0			
Chest	[illegible]	[illegible]	[illegible]	[illegible]					[illegible]	2.5	[illegible]		[illegible]	4.5	1.25	
Abdomen	[illegible]	[illegible]	0.50	[illegible]						1.30	2.2	[illegible]	[illegible]	2.22	[illegible]	2.10
Rt arm flex	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rt arm ext	[illegible]	[illegible]	[illegible]			[illegible]	1.25	[illegible]	[illegible]	[illegible]	[illegible]	1.20	.30	2.0	6.50	[illegible]
Rt forearm flex	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.15
[illegible]	[illegible]	[illegible]								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rt [illegible]	[illegible]	[illegible]	[illegible]								[illegible]	[illegible]				
Lt thigh inner surf	0.12	0.12	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.40	2.52
Rt leg outer surf	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lt leg inner surf	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.18	1.18	[illegible]	[illegible]	[illegible]	[illegible]	2.40
Forehead	[illegible]	1.12	1.2	[illegible] sl	[illegible] general [illegible]											

TABLE IV.

TIME RELATIONS OF TACHE IN SECONDS (0·1) AND MINUTES (1·0) AFTER HEAVY PRESSURE.

NAME.	Red appears.	White appears.	Red full.	Spread appears.	Spread full.	White full.	Spread gone.	Red fading.	Pal-pable.	Red still present.	Red gone.
BUTCHER 2 obs.	0·5	none	0·15	0·30	0·55	—	2·0	2·0		21·0	
ROBERTS 2 obs.	0·4	0·20	0·30	0·20		0·50		0·50		8·0	almost 8·0
GUEST 2 obs.	0·5 NOTE.	0·11 —Red	0·30 line bl	none uish at	— 1·15	0·50	—	1·5	3·25	30·0	almost 30·0
TETLEY 2 obs.	0·6	0·15	0·20	none	—	0·20	—	1·15	4·0	21·0	
BASHFORD 1 obs.	0·10	0·22	0·55	0·25	—	0·55	5·23	1·45		19·0	
SPENCER 1 obs.	0·8	0·18	1·10	—	—	0·47	—	—		7·0	
SHADBOLT 1 obs.	0·8	0·18	0·58	0·38	1·12	—	3·3	1·38		6·0	
DONELLY 1 obs.	0·6	—	0·55	0·20	—		3·0	2·45		13·0	
AVERAGE	6 sec.	17 sec.	41 sec.	27 sec.		44 sec.					

Relation to grade of stimulus, etc. In 10 subjects we noted the character of the tâche and its vividness from day to day and from week to week, making regular observations (Table II). We found few variations which might not be attributed to difference in the grade of pressure.

Notable variations in the reaction are witnessed with different grades of pressure.* In those patients who show a simple tâche, the brilliancy of the tâche is proportioned to the amount of pressure exerted ; in those who show a spreading tâche, the spread appears after heavy pressure, lighter pressure produces a simple red line. In patients who exhibit a red and white tâche, painfully heavy pressure usually induces a spreading flush around the tâche proper ; while very light pressure is almost invariably followed by the appearance of a simple white line. In these patients, if the pad of the finger or the end of a flat ruler is drawn across the back, a correspondingly broad band of pallor developes in the stimulated skin. On the other hand in patients who exhibit very vivid tâches or the simple form of spreading tâche, the pressure of the finger pad is either without effect, or produces a transitory red band.

* Prengowsky[6] and Müller[5] make the same statement.

It is clear that a strong stimulus and hypersensitive vessels are the two chief factors conditioning brilliancy of colouring; milder stimulation and less sensitive vessels condition paling. The stronger the stimulus, the greater the original congestion of the red line, and especially the more intense the surrounding flush, the more probable is the subsequent development of urticaria. The flush which spreads around many tâches is usually associated with painful stimulation; exceptionally it may appear when less pressure is exerted.

In a susceptible patient nothing is more remarkable than the sharp outline of a white band produced by stroking with the end of a flat ruler. The band of pallor is as sharp cut as though it had been painted on the skin in oils.

Time relations. Using a stop watch and working upon the skin of the back we noted the time relations of the tâche in a number of selected cases. The results are illustrated in Tables III and IV. The red line appears from 3 to 18 seconds after the commencement of stimulation, it may develop fully in as short a time as 15 seconds or may be delayed beyond a minute; usually it is at its height in from 30 to 50 seconds. It is fading very perceptibly at one to two minutes after stimulation and has disappeared after periods varying from 2 to 30 minutes, usually 3 to 8 minutes.

In cases where a red and white tâche develops, the white line appears later than the red, namely, at about 15 to 20 seconds after stimulation. It is at its height at the same time as the red line or a little later.*

The spread appears latest of all, namely from 20 seconds to more than a minute after stimulation; as a rule it has gone or has almost gone before the red line begins to fade. As compared with the red line, its onset is delayed and its offset is hurried in a given patient.

The white line of the red and white tache and the white band of finger pressure are of the same nature.

If in a suitable subject the pressure is exerted over symmetrical regions of the back, along one line heavy pressure with a blunt point and along the other light pressure with the finger—the heavy pressure yields a red and white tâche, the light pressure a white band. If the pressures are exerted simultaneously, the white line of the tâche and the white band are seen to appear simultaneously; they fade together and disappear at or about the same instant (Table V). The degree of pallor is the same in the two; both have sharp margins and margins parallel to the line of pressure. These facts suggest that the two constructions are similar in nature and origin. This view is confirmed by further observations. In cases where a red and white tâche surrounded by a spreading flush is obtained, if a line of light

* Accurate timing of full development is not possible.

pressure is drawn at right angles across it with the finger, the white band appears. This white band invades and obliterates* the areas of flush but does not affect the red line of the tâche (Fig. 2). Similarly, if the first tâche is disturbed by a second similar tâche drawn at right angles across it, the white line of the second tâche obliterates the flush of the first tâche where the two overlap. Thus the white line of the tâche and the white line of finger pressure influence the flush surrounding a tâche in similar fashion. We conclude that they are similar in nature, by which we mean that in the two instances blood vessels of the same order are constricted. We also believe

TABLE V.

Time relations of white tache with light pressure and white border of red tache with heavy pressure. In seconds (0·1) and minutes (1·0).

The tâches were produced simultaneously and over symmetrical areas of the interscapular region.

Name.		White appears.	White full.	fading.	Still present.	Just visible.	Gone.
Guest	Heavy press.	0·10	0·30	5·0	6·30	9·0	?
	Light press.	0·10	0·30	4·30	6·15	9·0	?
Kickevitz	Heavy press.	0·8	0·35	3·45	4·30	6·0	?
	Light press.	0·10	0·35	2·15	2·45	4·30	6·0
Spencer	Heavy press.	0·11	0·45	2·0	3·0	3·50	10·0
	Light press.	0·11	0·50	2·0	2·30	3·30	10·0

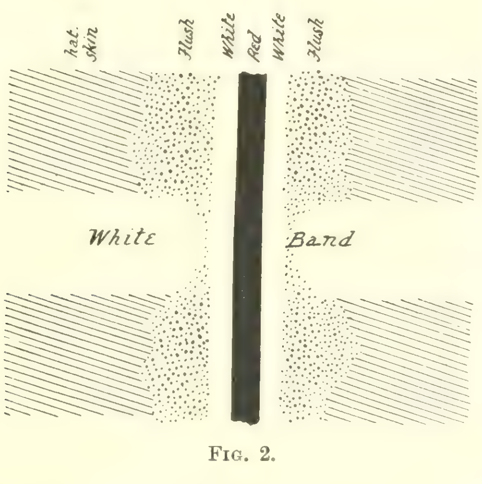


Fig. 2.

* Obliteration is often incomplete, the innermost portions of the flush may remain, while at the periphery and for some distance inwards blanching is conspicuous.

them to be produced in a similar fashion ; for when heavy pressure is exerted upon the skin, the weight falls chiefly upon the skin directly beneath the stroking instrument ; but the skin is depressed and stretched in immediately surrounding areas. This pull on the skin engenders a sufficient pressure stimulus subsequently to induce a vasoconstriction ; for slight stretching of the skin between two points with the fingers produces subsequent blanching of the skin area stretched. We shall attempt to locate this vasoconstriction at a later stage.

The red line of the tache and the flush of spread are distinct effects.

We were first led to this conclusion by observing the difference in the tint of the skin areas affected. The red line develops and at or about the time when it is full, it begins to assume a definite purple tint, clearly indicating a diminution of the oxygen content of blood within it. The flush does not vary in colour but maintains its pristine freshness throughout. The blood contained in it does not stagnate but is arterial so long as the flush remains. When the red line and the flush around it are contiguous, they may almost blend for a short space of time ; soon, however, the red line begins to acquire blueness and its edges are from that instant clearly defined and the contrast between the colour of line and flush quickly becomes conspicuous. The colour intensity is always uniform in the red line at a given moment ; the colour intensity of the flush is not uniform, the flush shows mottling with lighter tints of the same hue and this mottling is most conspicuous while the flush is fading. The edge of the tâche is straight when the line of pressure has been straight and the transition from red to white is relatively abrupt.* The edge of the flush is deeply crenated, and the transition to the skin colour is gradual. The red line spreads a uniform distance on both sides of the centre line of pressure ; it is confined to the immediate region of stimulation ; the edge of the flush is at a variable distance from this centre line and in many patients covers an area several inches in diameter.†

Again, the time relations of the two phenomena are different ; as described, the red line comes first and has the longer duration. The red line may continue to actual urticaria ; the flush has not been observed to do so.

When a white band is produced by finger pressure across a spreading tâche, the flush disappears or fades where there is overlap, while the red line is uninfluenced (Fig. 2). These facts, and others to be mentioned subsequently, convince us that we have to deal with reactions of distinct type.

---

* In patients whose skin reddens after very light stroking, the edge of the red line is not so clear, for in these the stretching of the skin induces redness in the neighbourhood of the red line proper. This diffusion should not be confused with the development of an outlying arterial flush.

† Müller[5] notes the difference and clearly distinguishes the two types of reaction.

The flush of the spreading tache is a similar effect to the flush which follows pin prick stimulation.

In the majority of our patients, if the skin is pricked with a pin sufficiently hard to produce pain, a flush is subsequently seen around the point so stimulated.* The area of the skin involved is usually as much as two centimetres in diameter, in some patients double or treble this measurement. The flush is the colour of arterial blood, has a crenated edge and is mottled, especially while it fades. It appears identical in colouration with the flush around a tâche when both are seen side by side in a given patient. If the back is pricked and stroked heavily at the same moment at symmetrical points the flush around the pin prick and tâche appear together,† they usually seem full at the same time ; they fade together (see Table VI).

TABLE VI.

Time relations of spread of tache and pin prick flush in seconds (0·1) and in minutes (1·0).

Name.	Red appears.	Red full.	Red fading.	Red gone.	No. of observations.
Guest					
Spread around tâche	1·0	1·52	2·30	6·30	3
Pin prick flush	0·31	1·50	2·34	4·25	
Roberts					
Spread around tâche	0·21	1·5	1·22	3·55	2
Pin prick flush	0·16	0·50	1·38	9·0	
Brooks					
Spread around tâche	0·19	1·03	1·16	3·36	2
Pin prick flush	0·19	0·54	1·16	3·45	
Bashford					
Spread around tâche	0·27	1·6	1·56	4·49	4
Pin prick flush	0·13	1·2	2·13	7·37	
Donnelly					
Spread around tâche	0·17	0·38	0·58	1·43	3
Pin prick flush	0·11	0·32	0·68	3·53	
Dixon					
Spread around tâche	0·15	0·48	1·10	3·30	1
Pin prick flush	0·15	0·52	1·15	6·50	

The blanching produced by finger pressure has the same influence upon the pin prick flush as it has upon the flush around the tâche ; it abolishes it and after the same time interval. For example, in one patient the skin was pricked and pressed upon simultaneously. The two flushes appeared together, namely at 25 seconds ; at 67 seconds from the start the finger was drawn across the tâche ; 98 seconds later the flush had just disappeared. At 85 seconds from the start the finger was drawn across

* Faradic stimulation and heat produce exactly similar effects.

† The pin prick flush appears a little earlier in some patients, probably because the pain stimulus is stronger.

the pin prick flush ; 95 seconds later it had just disappeared. Other observations fully confirmed this result. It is noteworthy that the flush around the tâche follows painful stroking especially and that it occurs in patients in whom the pin prick flush is vivid.

The flush around a tâche appears to be a reaction to pain ;* the red line of the tâche is independent of pain and is a reaction to pressure.

The vessels involved.

The red line of the tâche and the flush around it are due to engorgement of the capillaries of the skin ; such engorgement may be due to active dilatation of arterioles or of capillaries, or it may be due to a constriction of the venules. Now in the case of the pin prick flush or the spread around the tâche, the veins are clearly not involved, for the flush maintains an arterial colour. It is due therefore either to active capillary or arterial dilatation. Of the two causes, the second is favoured as an explanation for several reasons. The redness of the flush is brighter as well as deeper than that of the surrounding skin ; the colour is fresher, the blood is therefore more arterial. In a capillary dilatation one would anticipate, at the onset at all events, a simple deepening of the original tint. Further, were the flush a capillary effect, we should anticipate a uniform distribution of the capillaries affected ; we should expect that the spread would be to a uniform distance from the points of stimulation. The flush spreads irregularly, the margin is deeply crenated, it is also mottled. All these appearances are to be explained, as also is the slow gradation of colour at the actual margin, on the supposition that the arterioles dilate and that these arterioles supply adjoining or somewhat overlapping areas of skin.† There are additional reasons for assuming this cause. Adrenalin constricts the arterioles ; if the pin prick is placed over an area of pallor produced by this drug (injected subcutaneously in a 1 in 30,000 solution) the flush fails. Similarly the flush around a tâche fails to appear in an area previously affected by adrenalin. The arterioles‡ are already held constricted by the drug when the stimulus comes and the usual reaction is not seen. Both the flush of a pin prick and the flush around a tâche are abolished if adrenalin is injected beneath them. The flush of the tâche and of the pin prick also fails to appear if previously the circulation has been brought to a standstill by occluding the arterial supply ; this observation has been made upon the forearm.

There are reasons for believing that the white band of finger pressure and the white line of the tâche are purely capillary effects ; and the production of either of these forms of anæmia over a flushed area quickly whitens it. If the flushed area is due to arteriole dilation, the peripheral constriction of

* In this conclusion we agree with Müller[5].

† Müller[5] uses the same argument and to the same end.

‡ Probably the capillaries also (*vide infra.*).

capillaries would lead to this result.* We conclude that the flush is an arteriole effect.

In the case of the red line of the tâche, the original tint is that of the skin, but blueness is rapidly developed, indicating stagnation of the contained blood ; simple arteriole dilatation could not condition it ; it is due either to dilatation of capillaries or to constriction of venules. The uniform colour of the red line (the absence of mottling in it), the close correspondence between the area stimulated and the area involved, and especially the clear cut edge strongly favour the first hypothesis. It is scarcely conceivable that so uniform and clearly defined an area of redness could be conditioned by the participation of a number of small venules supplying adjoining areas ; the junctions of the small areas supplied by separate venules would surely be traceable, as we believe the junctions between the areas supplied by small arterioles are traceable in the mottled flush following a pin prick. We emphasise the exact correspondence between the area receiving pressure and the area which reacts and believe that such correspondence can only be explained by assuming the change to occur in the very smallest blood vessels.† A further reason for excluding the venules as a cause is the reaction of the same skin to lighter pressure ; the same region is stimulated, the same area reacts, but it reacts by paling and not by reddening. If it is supposed that the effects (the red and the white line) are produced in the capillaries, the white line may be attributed to capillary constriction following a weak stimulus, the red line by an excessive stimulus which paralyses them and induces dilation. If we attempt to explain the red line by supposing a change in the venules, then a change in the same vessels, even though it be of opposite kind, will not explain the development of pallor. Yet a common factor must be found if we are to understand why the red line of heavy pressure and the white line of light pressure have the same distribution relative to the line of stimulation. If the red line is due to a dilation of capillaries we have still to explain the loss of oxygen in the contained blood, as witnessed to by the onset of blueness. Certainly the blood would stagnate in the capillaries, but it is not equally clear that the rate of flow relative to the area of endothelium bounding the channels would be reduced ; probably with a conspicuous dilation of the capillaries more cells of the surrounding tissues are brought into contact with the expanded walls of these capillaries and the gaseous interchange becomes freer. That the capillaries are often damaged by heavy pressure is evidenced by the subsequent appearance of urticaria after the pressure has been applied.

If a line of pressure is run across skin blanched by adrenalin, the red line of the tâche develops in its whole length though the depth of tint is a little

* It may be argued that the same effect would be produced upon a capillary dilatation ; but the white line does not produce fading of the red line of the tâche when the two traverse each other, and the red line is almost certainly a capillary dilatation.

† This is the argument upon which Müller relies in concluding that the tâche is a direct capillary effect.

or considerably less where it crosses the blanched area. The capillaries are affected along the whole line ; they fill more freely and remain more fully distended, when the supply of blood from the arterioles is undisturbed. Similar effects are observed when the blanching is induced by applying cold until the skin is icy to the touch.

The sharp definition of the white band, produced by light stroking, first suggests its capillary origin ; this white band maintains its clear configuration for minutes until it fades. But our most conclusive evidence that the white band and the white line which surrounds a red tâche are really capillary effects has been obtained in the following fashion. The armlet of a sphygmomanometer is placed on the upper arm of a subject who is known to give a white line in response to light stroking of the forearm. The pressure in the armlet pressure is rapidly raised 70 or 80 mm. of mercury above the systolic blood pressure of the subject (*i.e.*, in a subject whose pressure is 120 mm., it is raised to 200 mm. Hg.) and maintained there. The forearm is subsequently stimulated by stroking lightly as in the control observation before obliterating the brachial vessel. The white line develops and is usually almost, if not quite, as vivid as before compression. By raising the pressure quickly* in the armlet both venous outflow and arterial inflow are abolished so far as the forearm is concerned, and after a short while the flow in all the vessels of the limb must cease. Nevertheless stimulation of the skin produces blanching ; the blood leaves the capillaries. In considering the white line produced while the arm circulation is intact, we have to choose between two hypothesis, contraction of the arterioles and closure of the capillaries. Now closure of the capillaries while the circulation stagnates still serves as an explanation ; but contraction of the arterioles, so it seems to us, cannot be entertained as an explanation in the circumstances of the present experiment. Such contraction of the arterioles while the circulation is free would rob the capillaries of their supply and would produce blanching of the skin providing that the capillaries emptied themselves in virtue of their elasticity ; but when the flow has ceased and the blood is stagnating in a system of vessels closed by the armlet above, contraction of the arterioles could not deplete the capillaries in this manner ; if such arteriole contraction affected the blood content of the capillaries, it could do so only in the direction of increasing it, blood being forced from arteriole to capillary. Blanching of the capillaries in these circumstances must be due to expulsion of the blood from the capillaries by a force acting on the capillary contents from outside and a force awakened in response to stimulation.

It may be argued that although the main veins and artery are occluded, a considerable time will elapse before equilibrium is established in the

* The success of this experiment is affected if in compressing the arm venous congestion is induced. A certain amount of venous congestion is usual if the limb compressed in the dependent position because the veins are occluded before the artery ; it is convenient first to raise the arm horizontally before compressing ; the arm should be of the same tint as the control arm immediately after compression.

vessels of different calibre and that the flow through arterioles and capillaries as the former empty themselves may be maintained for some while. It is in the highest degree improbable, considering the rapidity with which pressure falls in an artery shut off from communication with the heart, that there could be any flow in the small vessels after the lapse of 10 minutes ; yet blanching is obtained after compression has been maintained for that time. But for the sake of argument let us suppose that even then the flow has not quite ceased ; even so it cannot be denied that the rate of flow would be enormously diminished. If blanching is due to arteriole constriction and the cutting off of the supply to the capillaries, then the rate at which blanching occurs would be influenced by the rate of flow from the capillaries to veins at the moment of the reaction ; with a slow rate of flow blanching would take longer. Our observations show us clearly that the rate at which the white line develops is constant within the limits of observational error, whether the flow is natural at the moment of stimulation, or whether it has been slowing for 10 seconds, or for any period up to 10 minutes (Table VII). We are convinced therefore that the blanching is not of arteriole origin. Closure of the capillaries themselves alone suffices to explain the phenomena observed and we believe that this closure is affected by some essential element in the capillary wall. If it is suggested that the reaction may be due to contraction of such involuntary muscle fibres as are known to exist in the skin,* *i.e.*, those which erect the hairs, we reply that goose skin appears early after stimulation and long before the pallor has its onset, that contraction of these muscles does not induce material blanching and that the goose skin reaction has often completely subsided, if it appears, before the white line has developed fully. We are forced to regard the tissue elements immediately surrounding the capillary blood and forming an essential layer of the capillary wall as the source of the reaction.

A number of observers have believed that they have witnessed an active contraction of capillaries. Stricker[10] first stimulated the nictitating membrane of the frogs' eye and the tail of tadpoles and produced narrowing of the finest vessels. This observation has been confirmed by the work of Golubew[2] and Tarchanoff.[11] There has been divergence of opinion as to the nature of this contraction, whether local or general, and as to the tissue elements involved. Rouget's discovery[7] of spindle cells encircling the capillary wall by its outjutting processes, cells which are held by Mayer[4] to be continued from the contractile wall of the smallest arterioles, has given support to the hypothesis. In this country Roy and Brown[8] were the strongest advocates of the view. Recently a very suggestive paper has appeared under the names of Steinach and Kahn[9] ; these writers confirm the earliest results upon capillaries of the frog's nictitating membrane and have extended them ; they saw blood forced from both ends of a capillary responding to stimulation, an observation which seems to preclude such flow as may be secondary to pressure changes in the parent vessels. The latent period of contraction is about 3 seconds ; dilatation takes a longer while to come. These writers have seen similar events in the capillaries of the mammalion omentum. The evidence in favour of capillary contraction is weighty, and the burden of proof, so it seems to us, no longer rests upon those who hold that a change in the size of capillaries is active and not necessarily a passive response to changes in the vessels with which they are ultimately connected. A full account of past observations will be found in the papers cited.

---

* Lapinsky[5] attributed the white line to contraction of these muscles, constricting arteries and veins in the reticulated lamina of the skin.

TABLE VII.

APPEARANCE OF WHITE LINE AFTER BRACHIAL OCCLUSION.

Duration of arterial occlusion. (200 – 210 mm. Hg.).	Appearance of white line.		White line full.	
	SPENCER (B.P. 120)	GUEST (B.P. 122)	SPENCER	GUEST
0 secs.	12 secs.	15 secs.	20 secs.	25 secs.
10 ,,	10 ,,	13 ,,	15 ,,	30 ,,
1 min.	10 ,,	13 ,,	15 ,,	28 ,,
2 ,,	12 ,,	12 ,,	20 ,,	25 ,,
3 ,,	15 ,,	14 ,,	24 ,,	25 ,,
4 ,,	13 ,,	12 ,,	24 ,,	28 ,,
5 ,,	13 ,,	16 ,,	25 ,,	30 ,,
6 ,,	17 ,,	12 ,,	25 ,,	30 ,,
7 ,,	12 ,,	12 ,,	20 ,,	28 ,,
8 ,,	15 ,,	11 ,,	25 ,,	25 ,,
9 ,,	12 ,,	10 ,,	25 ,,	28 ,,
10 ,,	10 ,,	12 ,,	25 ,,	28 ,,

NOTE.—In both patients the two white lines obtained towards the end of the observations were somewhat less vivid than at the beginning.

We find additional support for this view in the following observations. If the skin of the natural forearm or hand is pressed upon and the pressure is rapidly withdrawn, the area of mechanical blanching quickly becomes suffused with colour again ; blood flows in from the neighbouring vessels, and, as may be seen, the in-flow is largely from the vessels of the skin surrounding the area blanched, for the colour returns to the edge of the white area first and the colour of the centre is often the last to be restored. It is to be supposed that the emptied capillaries are filled from the anastomosing capillaries unaffected by the pressure. Doubtless the empty vessels are also partly filled from deep lying arterioles supplying the blanched area ; but that the in-flow is largely if not chiefly from surrounding capillaries is known by the similar reaction after the circulation has been stopped in the limb. For our present purpose it is sufficient to assume that in a limb in which the circulation has been brought to a standstill the capillaries freely intercommunicate and that flow from one capillary network to an adjoining network will occur if the pressures in these capillary reservoirs are materially different. We raise the pressure in the armlet and occlude the circulation, subsequently creating in the skin two series of blanched areas, the one purely mechanical and the immediate effect of light pressure, the other a reaction

after a latent period to light stroking (the white tâche). We time the duration of blanching in the two series. The areas of mechanical blanching begin to suffuse immediately upon the release of pressure, and the area pressed upon becomes unrecognisable in a few seconds ; it is true that subsequent to compression of the brachial vessels the blanched area suffuses less rapidly ; the duration of the whitened area increases for a minute or a little longer after brachial occlusion, and then becomes tolerably uniform. It becomes uniform, so we think, when arterial flow completely ceases and when the in-flow is almost wholly from anastomosing capillaries ; however that may be, the blanched area is never long preserved.

The reaction to stroking is different ; the duration of the white line is to be measured in minutes. Whether the circulation has been obstructed or not, the white line stands out on the skin for a long while ; the capillaries may remain empty for as long as 6 minutes although they freely communicate with the capillaries in adjoining areas. Why is there no flow from these neighbouring vessels as there is when the area of blanching is purely mechanical ? There can be but one answer to this question ; blood cannot enter the affected capillaries because the pressure within them is as great or greater than that in the communicating vessels ; their contents are pressed by some external force.

TABLE VIII.

Duration of blanching before and after impeding the blood flow.

Duration of armlet occlusion. (220 mm. Hg.).	Onset of White tâche.	Duration of tâche.	Duration of mechanical blanching.*
0 min.	13 secs.	6 mins.	5 secs.
1 ,,	14 ,,	5 ,,	12 ,,
3 ,,	12 ,,	$4\frac{1}{2}$,,	24 ,,
5 ,,	13 ,,	$5\frac{1}{2}$,,	27 ,,
7 ,,	12 ,,	—	23 ,,
9 ,,	—	—	25 ,,

* Area three times the breadth of the tâche.

The measure of this force may be taken approximately in a given subject. Two armlets are used. One is placed upon the upper part of the forearm and its pressure is raised to from 15 to 40 mm. Hg. ; this pressure is maintained for 2 minutes or a little longer and the veins of the lower forearm become engorged correspondingly. In this way capillary pressure is raised to a level which is known within a small error of measurement. The second armlet* is placed upon the upper arm and is used to occlude the

* Two armlets are required to avoid further engorgement of the veins when the brachial vessels are occluded.

vessels. Working with the forearm engorged we test the degree of engorgement requisite to prevent the appearance of the white line as a reaction to light stroking. We find blanching to occur when venous pressure has been

TABLE IX.

APPEARANCE OF RED LINE AFTER BRACHIAL OCCLUSION.

Duration of arterial occlusion at 200 mm. Hg.	Appearance of red line.		Full red line.	
	COTTON (B.P. 125)	GODFREY (B.P. 122)	COTTON	GODFREY
0 sec.	10 sec.	8 sec.	50 sec.	20 sec.
10 ,,	11 ,,	15 ,,	65 ,,	40 ,,
1 min.	12 ,,	15 ,,	85 ,,	50 ,,
2 ,,	17 ,,	17 ,,	90 ,,	55 ,,
3 ,,	15 ,,	18 ,,	80 ,,	70* ,,
4 ,,	15 ,,	17 ,,	100* ,,	70* ,,
5 ,,	10 ,,	8 ,,	90* ,,	70* ,,
6 ,,	12 ,,	—	70* ,,	—
7 ,,	16 ,,	20 ,,	? 100* ,,	65* ,,
8 ,,	15 ,,	25 ,,	? 90* ,,	—
9 ,,	9 ,,	—	? 60* ,,	—
10 ,,	15 ,,	—	? 90* ,,	—
†	STUCKEY† (B.P. 125)	STEVENS† (B.P. 130)	STUCKEY	STEVENS
0 sec.	15 sec.	16 sec.	60 sec.	42 sec.
10 ,,	10 ,,	29 ,,	60 ,,	85 ,,
1 min.	15 ,,	24 ,,	90 ,,	80 ,,
2 ,,	20 ,,	12 ,,	100 ,,	93 ,,
2 ,,	18 ,,	21 ,,	115 ,,	105 ,,
5 ,,	30 ,,	22 ,,	150 ,,	135 ,,
5 ,,	20 ,,	26 ,,	140 ,,	125 ,,
6 ,,	17 ,,	20 ,,	120 ,,	125 ,,
7 ,,	25 ,,	33 ,,	?	?

* Red lines of less intensity.

† In neither of these cases was there an appreciable diminution in the intensity of the red line up till the 6th minute. The arms were congested by raising venous pressure before occlusion of the artery.

raised to as much as 30 mm. of Hg., and conclude that the capillaries are capable of exerting an active constrictive force of at least this amount in some subjects.

Experiment. Lower armlet raised to 30 mm. and maintained for 2 minutes. Upper armlet then raised to 200 mm. and maintained for 2 minutes. Light stroke over lower forearm produced a distinct white reaction after a latent period of 1 minute. The observation was repeated and a positive result obtained with the lower armlet pressure at 30 mm. and at 23 mm.. With the lower armlet at 40 and 45 mm. the reaction was doubtful; at 50 mm. it did not occur. Capillaries capable of exerting an active pressure of at least 30 mm. Hg..

A heavier stroking of the arm after occlusion of the main vessels of the limb is followed by the development of a red line which varies in intensity in different observations. Sometimes it is vivid, sometimes less vivid by comparison with the control upon the arm when the circulation is free. It will be clear that after cessation or conspicuous retardation of the blood stream, the rapid development of a red line cannot be explained by relaxation of the arterioles; contraction of the venules is scarcely more plausible, for although it would introduce an impediment to the blood flow in normal circumstances, in the new circumstances there would be little or no flow to obstruct.* It is conceivable that contraction of the venules might force some blood in a retrograde direction and the capillaries might thereby be engorged to some extent, but the chief flow from the veins would still be into the larger veins, the direction of least resistance, and if some blood entered the capillaries from the veins it would not confine itself to a few capillaries, but would spread into others and even back into the arterioles. However that might be, the reaction could not approach the reaction in the fully nourished arm, either in rate or in intensity, as is observed to be the case (Table IX). Relaxation of the capillary wall forms a more acceptable hypothesis, for it would lessen the tension on the capillary contents and permit an inflow from arterioles, anastomosing capillaries, and may be the venules also. This is the view which we accept. The variation in the apparent intensity of the red line reaction and in the rapidity of its development after cessation of the blood flow is due in our view simply to the amount of blood left in the arm when the circulation is stopped. If the armlet pressure is raised while the arm is held high above the head, and the arm is then lowered and stroked, no red line is seen, for the arm by this procedure is depleted of blood; if the arm is held less high the red line is slight; if the arm is held dependent the red line is vivid, for the arm thereby is somewhat engorged. If a normal amount of blood is left in the arm, as judged by a comparison of the general tint of the skin with that of the control arm, the red line is seen; but there may be some

* Lapinsky[3] takes the view that the venules are obstructed by contraction of the involuntary muscle of the skin, such as the pilomotors. His view has as far as we can see purely anatomical evidence to support it. We cannot confirm Lapinsky that goose skin and the red line are connected, the former materially precedes the latter and is of much shorter duration. The red line is to be obtained over the skin of the penis where there are no hairs. The prominence of the tâche and of goose skin do not run hand in hand.

delay in its appearance and in vividness it may not develop fully, and this is especially the case if the blood flow has been long obstructed. The development of the red line is clearly dependent upon the transference of blood from surrounding vessels, and the depth of its tint and the time of development are conditioned by the freedom with which the blood flows from these neighbouring stagnant reservoirs.

The flush surrounding a tâche, which we believe to be the effect of arteriole dilatation is abolished, as has been related, after the circulation has been brought to a similar condition of standstill; but relaxation of the arteriole wall is not abolished as is shown by the phenomena witnessed when the armlet pressure is quickly reduced to zero. The whole arm is at once suffused, the flush after a short interval confining itself to the region of previous stimulation. It is the emptiness of the arteries which prevents the appearance of the flush in the first place.

When adrenalin has been injected under the skin and a red tâche develops by stroking heavily, the reduced depth of the tâche immediately over the blanched area is to be explained partly in a like fashion. Here also the supply of blood to the capillaries, dilating as a reaction to the stroke, is diminished and is insufficient fully to engorge the capillaries; it may also be conditioned in part by a direct action of the drug upon the capillary wall, namely, by its contraction.

The blanching of adrenalin.

If a few drops of a 1/30,000 adrenalin are injected beneath the skin, an intense blanching shortly appears around the site of injection. This blanching is distinct from the slight initial pallor, the mechanical result of the injection. It begins to appear in the normal subject in about 15 seconds to one minute, it is of full intensity in about 1—3 minutes. This blanching is due according to current views to a contraction of the arterioles. That arteriole contraction plays its part we do not doubt, but we believe that the capillaries are also affected and affected profoundly. We obtain blanching of the forearm as a reaction to adrenalin after occluding the vessels of the upper arm. The blanching is almost as intense or quite as intense as before occlusion providing that the injection is very superficial; the reaction is to be obtained conspicuously 5 or more minutes after the circulation has been brought to a standstill. We cannot conceive that constriction of any vessels other than those which are responsible for the natural colour of the skin could blanch the skin in these circumstances; for equilibrium of pressures has developed in the vessels and capillary flow has presumably ceased. We have attempted to take the times of onset and full development of blanching before and after the occlusion of the main vessels; but the time reactions vary so much in different observations that we can draw no conclusions from the results, other than to state that there is no appreciable delay in the

appearance of blanching after the main vessels have been obstructed. The blanching of skin following an adrenalin injection into the arm in which the circulation is maintained is not conditioned solely by a lack of supply to the capillaries; depletion of the capillary contents by an increase in pressure upon them is also a factor. The pilomotor reaction and the blanching are not simultaneous in onset; the former consequently is not responsible for the latter.

BIBLIOGRAPHY.

[1] FAUCONIER. Congres internat. d. Brux.-Liege., Brux., 1911. (Cited by Lapinsky.)

[2] GOLUBEW. Archiv. f. Mikroskop. Anat , 1869, v, 49.

[3] LAPINSKY. Zeitschr. f. d. ges. Neurol. u Psych., 1914, XXII, 58.

[4] MAYER. Anat. Anz., 1902, XXI, 442.

[5] MULLER. Deutsch. Zeitschr. f. Nervenheilk., 1913, XLVII-VIII, 413.

[6] PRENGOWSKY. Archiv. f. Psych., 1906, XLI, 746.

[7] ROUGET. Comb. Rend. hebdo. d. l'acad. d. sc., 1879, LXXXVIII, 916.

[8] ROY & BROWN. Journ. of Physiol., 1879-80, II, 323.

[9] STEINACH & KAHN. Archiv. f. d. ges. Physiol., 1903, XCVII, 105.

[10] STRICKER. Sitzungsb. d. k. Akad. d. Wiosens., 1865, LI, II, 16, *ibid*, 1876, LXXIV, III, 313.

[11] TARCHANOFF. Archiv. f. d. ges. Physiol., 1874, IX, 407.

[*Reprinted from "Heart."*
Vol. VI, No. 4, July, 1917.]

INTIMAL KELOID-LIKE THICKENING OF THE FEMORAL AND EXTERNAL ILIAC ARTERY, AND ITS RELATION TO ARTERIOSCLEROSIS.

By Dr. Med. MAX des LIGNERIS.

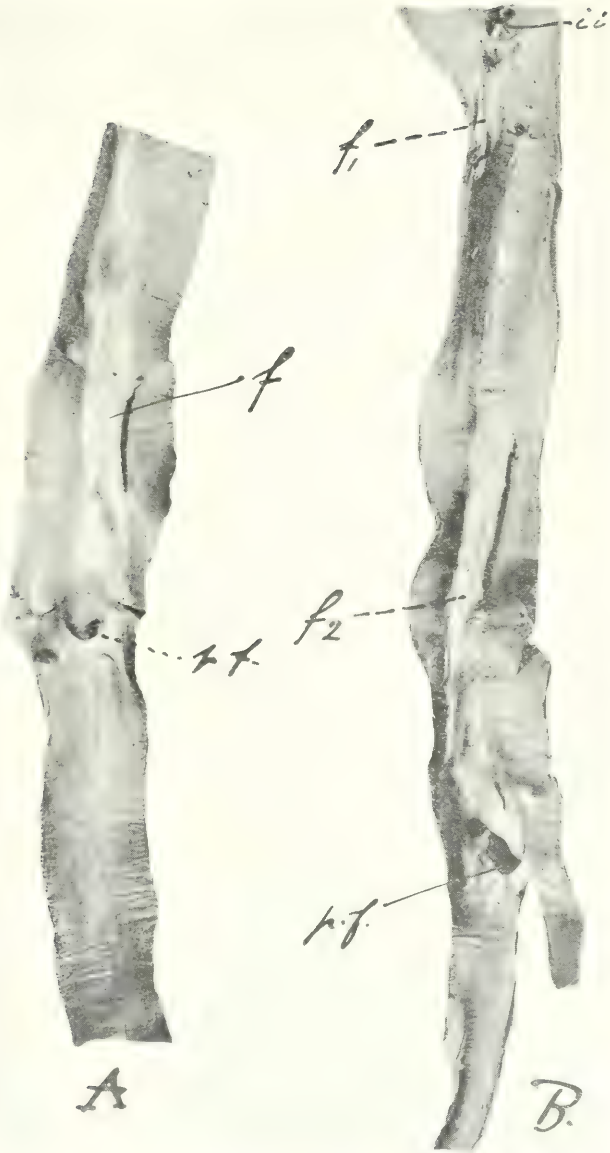
(*From the Pathological Institute, Basle.* Director, Prof. Dr. E. Hedinger.)

In the following pages a special form of sclerosis of the intima, situated in the upper part of the femoral and in the external iliac artery, is described. This sclerosis was first seen at a very advanced stage in a post-mortem upon a case of lithiasis of the pancreas with diabetes. Since its discovery I have been looking for similar cases in all the post-mortems of the Basle Pathological Institute and have seen similar, though less severe, alterations in a great number of cases. I shall first describe the main case, and then summarise a hundred post-mortems, describing the aspect of the intima in similar, though less advanced cases and, having done this, shall inquire into the pathogenesis of these special changes and their relations to arteriosclerosis generally.

On September the 14th, 1915, a post-mortem examination was performed on the body of a man, 54 years old. The clinical data were as follows: The patient, by profession a stationmaster, had been laparotomised for a pancreatic affection, and after this costectomised for a subsequent empyema of the right pleural cavity. He had sugar in the urine, and a chronic ascites. There was no suspicion of syphilis in the clinical history. Wassermann reaction was negative. At the post-mortem lobular pneumonia of the inferior lobe of the right lung, total synechia of the pericardium, brown atrophy of the heart, fibrous myocarditis, hydrothorax and ascites, cirrhosis of the pancreas with a considerable number of concretions, and chronic fibrous leptomeningitis accompanied by internal hydrocephalus were found. The aortic valves were slightly thickened at the base, the intima of the whole aorta was in the most places quite normal. Round the origin of the intercostal arteries and some others there was a slight thickening of the intima with very slight atheromatosis. The abdominal aorta had in its inferior part a circumference of $4\frac{1}{2}$ to 5 cm.. The appearance of the intima was the same as in the superior part. When opened, the external iliac and the femoral arteries on both sides showed a very striking picture, as shown in the

illustrations. The left external iliac artery had a circumference of 19 to 21 mm.. The greater part of the intima presented a normal appearance. But the back wall, where the artery lies on the edge of the psoas muscle, was covered on the inner side by a white veil resembling a band of fibrous tissue. This formation started from the middle part of the external iliac artery and, everywhere covering the back wall of the artery, reached the upper part of the femoral artery just underneath the origin of the art. profunda femoris. The breadth of this band of tissue was about 6 mm.; it consisted of a broad central, longitudinal, slightly prominent range and a thinner shelving border; the latter had a somewhat transversally striated appearance. The line of transition between the band and the normal intima was not everywhere very distinct. The lateral border of the band, between the origin of the art. epigastrica inferior and the art. profunda femoris, was detached from the underlying wall for a length of 18 mm. forming a sharp edge of 2-3 mm. height which was somewhat recurved towards the centre of the arterial lumen. Everywhere else the border of the fibrous band lay level with the intima. Lower down the middle of the strip presented a scarlike shallow trough of about 10 mm. length. Still lower the white band became a little broader and surrounded the origin of the profunda femoris, ending 3 mm. beneath in a crescentic edge. The right femoral artery had the same circumference as the left and showed similar appearances. The strip was similarly situated, though the lesion was in an even more advanced stage. On this side were two distinctly separated longitudinal fibrous areas. The first or upper band began in the common iliac artery, covering its posterior wall as a thin whitish veil, thickening as it descended from the origin of the internal iliac artery and forming in the external iliac artery a distinct white band. 4-5 mm. below the origin of the internal iliac artery the internal border of the band was detached for a length of 18 mm., and a sharp prominent edge of 3-4 mm. height was formed. The base of this edge had a breadth of 3 mm.. Lower down both borders of the fibrous band lay flush with the intima, a central ridge and a peripheral transversally striated part were distinctly visible. This upper fibrous band had a total length of about 35 mm. and it ended in the middle of the external iliac artery. At the same height, but more laterally and separated from the first by a narrow area of normal intima, a second band originated, and extended down along the posterior wall of the external iliac and femoral artery; its length amounted to 90 mm.. The macroscopical appearance of this band resembled that of the other. At two places one of the borders, at first the external and lower down the internal border, were detached for a length of 27 mm. -5 mm. respectively from the underlying arterial walls. The lower end of the band lay 5 mm. below the origin of the profunda femoris, surrounding the origin of this vessel by a fibrous thickening.

From the fibrous bands and neighbouring arterial walls transversal and longitudinal pieces were excised, fixed in formol solution and frozen sections



A.	Left external iliac artery.
f.	Fibrous stripe.
p. f.	Art. profunda femoris.
B.	Right external iliac artery
f_1	First or upper stripe.
f_2	Second or lower stripe.
p. f.	Art. profunda femoris.
i. i.	Internal iliac artery.

as well as celloidin blocks made of. The sections were stained with Hemalun-Eosine, with Sudan, by the Van Gieson method, by Weigert's elastin method, with Orcein, by Dürck's "Gitterfasern" method (modification of Weigert's colouration of myelin) and by Löele's modification of Mallory's method.

Microscopical appearances. The arterial wall of the iliac and femoral artery outside the region of the lesion consisted of the usual three layers: the intima showed the normal physiological appearances of an artery in a middle-aged man, *i.e.*, the membrana elastica interna was split up into at least 2, sometimes 3-4 elastic formations, which showed sometimes short interruptions. The deeper elastic membrane, which covered the media, had a homogenous appearance in its centre taking up colours well; it was regularly twisted. The detached elastic layers nearer the endothelium were sometimes broader, their borders showing irregularities in transverse sections. (Sections cut through longitudinal elastic fibrils, which lay on the detached membranes.) Between the split up parts of the elastic membrane lay some longitudinally situated muscular fibres and also connective tissue. The intimal thickening, apart from the fibrous bands, nowhere exceeded that found in healthy subjects of the same age. The media had an average thickness of 0·75 mm. and consisted of transversely lying muscular fibres with a considerable number of elastic fibrils; the latter were somewhat twisted and showed radially arranged "Gitterfasern." The connective tissue in the media nowhere predominated over the muscular and elastic tissue. The adventitia consisted of a considerable number of thick elastic and connective fibres, and of vasa vasorum.

The arterial wall showed no signs of degeneration of any kind (fatty, hyaline, etc. . . .); neither infiltration with lymphocytes or other blood-cells, nor accumulation of fibroblasts nor the penetration of vasa vasorum into media or intima were to be found.

The sections through the fibrous bands showed them to consist of an enormous localised connective tissue formation of the intima. The intima became abruptly 50-100 times thicker, and reached 3 mm.. It consisted, under a normal layer of thin endothelial cells, of a great number of thick connective tissue fibres of a definite eosine-red, resp. fuchsin-red colour in stained sections. The fibres lay in different directions: transverse, longitudinal or oblique. The appearance was that of a dense, homogenous mass, resembling hyalin. Between these fibres lay a variable amount of cellular elements, of the nature of connective tissue cells, elongated and spindle shaped. A comparison between the longitudinal and the transverse sections made it clear that the greater part of these cellular elements lay with their long diameters along the lumen of the artery, though a few lay transversely or obliquely. In some parts of the fibrous intimal thickening the cellular elements were very scarce; in other parts more numerous, but nowhere in great number. Some of the spaces between the connective tissue fibres were not wholly filled with these cells, a pericellular space, staining bluish with hemalum or yellow with picric acid, overrounded the latter. Some of these interfibrous spaces seemed to contain no cells, but this ill-defined material only. The deeper, older layers showed more interfibrous spaces and more of this bluish material than the younger layers which lay nearer to the lumen of the artery.

On transverse sections the fissuring of the elastic membranes reached a high grade at the spot where the fibrous thickening of the intima starts. The elastic membrane was split into dozens of single elements. Some of these could be followed into the deeper layers of the intimal thickening, where becoming even more separated they seemed to disappear before reaching the maximal intimal thickening. Some of them, situated in the neighbourhood of the media, traversed the thickening, but not without several interruptions. Some of these interruptions can be considered as enlarged fenestræ, some were probably real ruptures, the ends of the fibres being generally turned towards the arterial lumen. The deepest elastic membrane which resembled most of all a normal elastica interna was usually quite stretched, or at least much less twisted than a normal elastica, and in many places interrupted, but preserved sufficient structure to outline the intima from the media. This elastic membrane was also thinner than normal. The neighbouring elastic layer, the first inside the intimal thickening, was much thicker, generally twisted, much interrupted and ruptured and showing degenerative changes. The normally homogenous broad internal mass of the elastic layer was divided up into more or less short segments with irregular outlines. Some segments took up stains intensely, others very weakly. With Sudan this layer appeared to contain a considerable number of small drops of fat. The other elastic elements, more deeply situated, showed also some, though less, fatty degeneration. The remaining portion of elastic layer, *i.e.*, that adjoining the media, showed no fatty degeneration. There were also some few drops of fat in the deepest layers of the intimal thickening between the elastic elements; they were situated within the interfibrous spaces above described.

Besides the elastic layers there were in the deeper layers of the intimal thickening some thin, more or less twisted, short elastic fibrils, perhaps representing a new formation of elastic elements.

Not only the elastic elements of the hyperplastic intima, but also the muscle fibres of the normal longitudinal elastico-muscular layer, showed well marked changes. Some remaining

muscular cells or muscular nuclei were still visible, but they were scarce, and between them a considerable mass of thick homogenous fibres, which by their colouration could be recognised as connective tissue fibres, perhaps already hyalinized, could be seen.

Nowhere in the fibrous intimal thickening could leucocytes or lymphocytes be found, nowhere vasa vasorum. Nowhere could any pigment be seen, as would probably be the case if the fibrous band was an organised thrombus. The intimal thickening turned a convex surface not only towards the lumen, but also towards the media. The latter was compressed to about half the thickness of the natural media. All the elements of the media showed the results of compression. The muscular and connective tissue as well as the elastic fibres were thin, stretched out and decreased in number. " Gitterfasern " could not be made out. A few of the muscular fibres contained, in prolongation of the nuclei, some small fat drops. Whilst the neighbouring media contained no vessels, there were in nearly every section one or two small vasa vasorum, which had entered the media from the adventitial side These vasa vasorum consisted of an angiothel with a small adventitia. Lymphocytes in the media were very scarce. Leucocytes could not be found. In a very few sections a small focus of calcification could be seen within the media under a border of the intimal thickening. The adventitia seemed to be normal.

How can we explain the detachment of the border of the intimal thickening from the underlying wall ? The deep layer of the intima was softened by the fatty degeneration found within the elastic elements and the connective tissue, and by the enlarged interfibrous spaces containing necrotic material and apparently an increased quantity of fluid. It is not surprising, if the movements of the leg and those resulting from the blood-pulsation caused a discontinuity in this situation. That this detachment was not a post-mortem event is clear, as in some places the elastic fibres near the border of the intimal thickening and within the latter were discontinuous with these of the neighbouring normal intima and were incurved towards the lumen, as was also the intima freshly detached from the media after rupture of the elastic elements at that place. That this rupture had also happened during life was shown in sections in which these broad spaces between the ruptured elastic elements were filled by a fibrous tissue with no elastic elements in it, tissue of a similar character to that of the main intimal thickening. Thus the rupture was filled up with simple scar tissue.

How is this apparently unusual and considerable local thickening of the intima to be explained ? There were no signs of syphilis, the general structure seems to exclude with certainty the possibility of a lateral thrombosis ; there was but little arteriosclerosis in the main arteries. Where plaques were found in the large arteries of this patient, they were much more of the sclerotic rather than of the atheromatous type of degeneration.

In order to ascertain whether the pictures seen in this case are quite unusual, or whether cases of a similar though perhaps less advanced type sometimes occur, I have examined thoroughly not only the aorta but also the iliac and femoral, sometimes also the popliteal, arteries in our post-mortems, and soon discovered that these arterial changes are not at all unusual, and that slight degrees of the same change are found at similar places in a great number of post-mortems, even in very young subjects, and quite independently of atheromatous degeneration in the aorta and other big arteries. But I never found in one hundred consecutive post-mortems examined ad hoc, such long fibrous bands. The thickenings, when present, were nearly always located just beneath Pourpart's ligament, between the origin of the art. epigastrica inferior and the art. profunda femoris. Their average length was about 30-40 mm.. The results of the investigations are summarised in the tables.

Thus, in one hundred consecutive and unselected cases, we found in not less than 33 per cent. changes in the intima of the femoral artery, similar to the above described, though usually much less advanced. We only

count the cases where the intimal thickening was not accompanied, macroscopically, by notable degrees of atheromatous changes. Ordinary arteriosclerotic changes with both sclerosis and atheromatosis were found in not less than 79 per cent. of the post-mortems, *i.e.*, in the aorta (very slight and slight in 39 per cent., medium in 14 per cent., severe in 26 per cent.). In the upper femoralis, ordinary arteriosclerosis, similar (though usually somewhat less severe) to the changes in the aorta, was found in 30 per cent. of all cases (26 per cent. with sclerosis and atheromatosis, 4 per cent. with atheromatosis alone). An absolutely normal aorta was found in 21 per cent., an absolutely normal upper femoralis in 29 per cent.. Here we must point out that an absolutely normal aorta does not include an absolutely normal femoralis, *i.e.*, a femoralis with no macroscopical intimal thickening. On the other hand, normal femorales could be found in cases where there were arteriosclerotic changes in the aorta.

From the 33 per cent. of cases presenting intimal thickening of the femorals :—

6 per cent. were very slight ;

19 per cent. were slight ;

3 per cent. were more advanced in degree without and

5 per cent. were more advanced in degree with very slight atheromatous degeneration.

The slight degrees of intimal thickening form the best approach in studying the pathogenesis of the more advanced cases. We study the first changes in a normal thin intima (or in a normally hyperplastic intima in an older subject) of the upper femoral artery.

In the cases of very slight intimal thickening the only differences between normal hyperplastic conditions and our cases consist in the development of fibrous tissue between the elastic fibres. We have studied carefully the conditions of the elastic elements, especially on account of the question of primary or secondary degeneration of these elements. We have found cases of intimal thickening where under the fibrous intima the elastic elements were not at all involved in fatty degeneration. It therefore appears that the fatty degeneration of the elastic elements, though present in most cases of intimal thickening, does not play an essentially primary part in the formation of the intimal changes. But in all cases we found a multiplication of the elastic membranes, especially in the region situated under the lateral parts of the intimal thickening, whilst under the central parts, where the intima is most thickened, a good many of the elastic elements seem to have disappeared and the remaining ones are thin and stretched and have lost their continuity in many places. We found that this first elastic membrane, the one which touches the media, though often interrupted by large spaces where connective tissue from the media seems to enter the intima, is generally

TABLE.

Age and Sex.	Pathological diagnosis.	General appearance of arteries (aorta, etc.).	Appearances of femoral arteries just beneath the ligament-Pourparti.	
			Macroscopical.	Microscopical.
18 y. ♂	Tuberculosis of lungs and larynx; atrophy of heart.	A certain number of sclerotic plaques in aorta with slight atheromatosis.	Band-like thickening of intima, slight degree.	Thickening of intima with fatty degeneration and loose tissue at the base.
55 y. ♀	Tabes dorsalis; bronchopneumonia; cysto-pyelo-nephritis.	Slight general sclerosis; very little atheromatosis.	On both sides white band-like thickening of intima, no atheromatosis.	Thickening of intima without fatty or calculous degeneration.
70 y. ♀	General arteriosclerosis and obesity; myocarditis fibrosa.	Severe form of sclerosis with atheromatosis and calcification	Same as general appearances of arteries.	Not examined.
3½ y. ♀	Diphtheria; bronchitis.	Normal.	Normal.	No degeneration; intima thin, but in most places elastica interna doubled.
39 y. ♂	Anthracosis of lungs with bronchitis and pleurisy.	Slight sclerosis, most pronounced in pulmonal artery; in the latter also atheromatosis	Slight band-like thickening; very slight atheromatosis.	Not examined.
0 y. ♂	Still-born child.	Normal.	Normal.	Not examined.
48 y. ♀	Ulcer of the stomach with hæmorrhage; emphysema pulmonum; bronchitis.	Very slight general sclerosis and atheromatosis.	Whitish slight thickening of intima.	Slight thickening of intima; at the base very slight degeneration.
2 days ♂	Congenital heart disease.	Normal.	Normal.	Not examined.
8 days ♂	Tetanus neonatorum.	Normal.	Normal.	Not examined.
34 y. ♂	Gastroenterostomy; atrophy of heart; thrombosis of prostatic veins.	Very slight atheromatosis of aorta.	Very slight whitish thickening of intima.	Slight thickening of intima, especially where lateral branches start; no degeneration.
69 y. ♀	Multiple tuberculosis; general arteriosclerosis.	Severe form of sclerosis and atheromatosis of big arteries.	Same as other big arteries.	Not examined
63 y. ♂	Carcinoma œsophagi with perforation; pneumonia and pleurisy.	Slight sclerosis and atheromatosis.	Very slight whitish thickening of intima.	Not examined.

71 y. ♂	Lobar pneumonia; emphysema of lungs; general arteriosclerosis.	Pretty severe form of sclerosis and atheromatosis.	Same as other arteries.	Not examined.
70 y. ♂	Peritonitis after strangulated hernia; general arteriosclerosis; cirrhosis of liver.	Severe form of atheromatosis with thrombosis.	General thickening and atheromatosis of arteries.	Not examined.
61 y. ♀	Severe burns.	A considerable number of sclerotic and atheromatous plaques.	Band-like white thickening of intima.	Not examined.
37 y. ♂	Bright's disease; hypertrophy of heart.	Slight sclerosis and atheromatosis.	Band-like white thickening of intima.	Thickening of intima, most pronounced at departure of branches, no degeneration.
65 y. ♀	Carcinoma of gall-bladder with multiple metastases.	Mesaortitis luetica, no atheromatosis.	Very slight white thickening of intima.	Slight thickening of intima, most pronounced at departure of branches; no degeneration.
82 y. ♂	General arteriosclerosis; emphysema of lungs.	Severe atheromatosis and calcification of aorta and big vessels.	Same as other arteries.	Not examined.
0 y. ♀	Foetus maceratus imbibitus.	Normal.	Normal.	Not examined.
66 y. ♂	General arteriosclerosis; haemorrhages into the brain.	Severe general sclerosis and atheromatosis.	White thickening of intima.	Not examined.
0 y. ♀	Foetus maceratus imbibitus.	Normal.	Normal.	Not examined.
76 y. ♀	Carcinoma of right ovary with multiple metastases.	Very slight sclerosis and atheromatosis; a few calculous foci.	Slight atheromatosis.	Not examined.
10 y. ♂	Multiple tuberculosis and amyloidosis.	Slight atheromatosis of aorta.	Normal.	Not examined.
47 y. ♂	Carcinoma of upper jaw with metastases in lungs and gangrenous pneumonia.	Very slight sclerosis and atheromatosis.	Slight thickening (whitish) of intima.	Not examined.
5 y. ♂	Measles; congenital heart disease; bronchopneumonia.	Normal.	Normal.	Not examined.
66 y. ♂	Carcinoma of urinary bladder; nephritis subacuta.	A number of plaques, sclerotic and atheromatous.	Slight thickening, with a few atheromatous patches.	Not examined.

TABLE—*continued.*

Age and Sex.	Pathological diagnosis.	General appearance of arteries (aorta, etc.).	Appearances of femoral arteries just beneath the ligament-Pourparti.	
			Macroscopical.	Microscopical.
57 y. ♂	Fibrous pleurisy with bronchiectasies, atelectasis of lungs.	Slight sclerosis and atheromatosis.	Very slight white thickening of intima.	Not examined.
29 y. ♂	Fracture of skull with extradural hæmatoma.	With exception of a small patch of thickening of intima at the arcus aortæ all the big arteries are normal.	Slight white thickening of intima.	Intima in the patches slightly thickened, considerable new formation of elastic fibres; no degeneration of intima; in the media quite a number of foci of calcification.
30 y. ♀	Chronic endocarditis valv. mitral. stasis in lungs and most organs.	Aorta without atheroma; Pulm. artery with sclerosis and atheromatosis.	Slight thickening of intima.	Thickening of intima; no fatty degeneration; beginning calcification of deep layers of thickening.
74 y. ♀	General arteriosclerosis with emphysema and hypertrophy of heart.	Severe form of atheromatous degeneration (with ulceration) of aorta and big arteries.	Sclerosis and atheromatosis of femoral arteries.	Not examined.
33 y. ♀	Lobar pneumonia with infarcts of lungs and thrombosis of pulmonal artery.	Slight atheromatous patches in aorta.	A few very small atheromatous patches.	Not examined.
5½ y. ♀	Multiple traumata, beginning tuberculosis of lungs.	A few small atheromatous patches in aorta ascendens, other arteries normal.	Normal.	Not examined.
7 m. ♂	Laparotomy for intussusception of ileum and coecum; general debility.	Normal.	Normal.	Not examined.
81 y. ♀	Bronchopneumonia; emphysema; general arteriosclerosis.	Severe atheromatous degeneration and ulceration.	White thickening of intima with a few yellow patches.	Thickening of intima with patchy fatty degeneration of deeper layers; many foci of calcification in the media.
78 y. ♂	Lobar pneumonia and pleurisy; genital tuberculosis.	Sclerosis and atheromatosis of all big arteries.	Same as other arteries.	Not examined.

3 w.	♂	Peritonitis after infection and thrombosis of the umbilical vein.	Normal.	Normal.	Not examined.
81 y.	♂	General arteriosclerosis; atrophy of kidneys; hæmorrhages into brain.	Severe atheromatous and calculous degeneration of big arteries.	Atheromatous patches and calcification.	Not examined.
85 y.	♀	Emphysema of lungs; bronchitis; arteriosclerosis.	Atheromatosis and calcification of big arteries.	Same as other arteries.	Not examined.
38 y.	♀	Chronic endocarditis valv. mitr.; Bright's disease. Thrombosis of cerebral arteries.	Very slight sclerosis and atheromatosis.	Slight thickening of intima, especially on the right side.	Slight thickening without degeneration of the intima; a few calculous foci in the media.
63 y.	♂	Perforation of aorta into left pleural cavity; general arteriosclerosis.	Atheromatosis and calculous degeneration of aorta and big arteries.	White thickening with atheromatous degeneration.	Thickening of intima with fatty and calculous degeneration of deep layers of intima.
53 y.	♀	Carcinoma of the breast, with multiple metastases.	A number of sclerotic and atheromatous patches.	Slight white thickening of intima.	Not examined.
18 y.	♂	Fracture of the skull; extradural hæmatoma; contusio cerebri.	A few atheromatous patches in the aorta.	Normal	Not examined.
43 y.	♀	Diabetes mellitus: atrophy of pancreas; endocarditis chronica.	A considerable number of sclerotic and atheromatous patches in aorta and big arteries.	White thickening of intima.	Considerable thickening of intima; many interruptions of elastic membranes; atrophy of media; slight fatty degeneration of deep layers of intima
76 y.	♂	General arteriosclerosis; bronchopneumonia; atrophy of kidneys.	Severe atheromatous and calculous degeneration of aorta and big arteries.	Same as other arteries.	Not examined.
37 y.	♀	Purulent thrombophlebitis of femoral veins; sepsis.	Very slight atheroma of the arcus aortæ.	Normal.	Not examined.
60 y.	♀	Emphysema of lungs; chronic pleurisy and pericarditis; hypertrophy of heart.	A number of sclerotic and atheromatous patches in aorta.	White thickening of intima.	Slight thickening of intima; no degeneration.
20 y.	♀	Bright's disease; bronchopneumonia; parotitis purulenta.	Normal.	Slight white thickening of intima.	Slight thickening of intima; no degeneration.

TABLE—*continued.*

Age and Sex.	Pathological diagnosis.	General appearance of arteries (aorta, etc.).	Appearances of femoral arteries just beneath the ligament-Pourparti.	
			Macroscopical.	Microscopical.
66 y. ♀	Osteomalacia; Bright's disease; peritonitis purulenta.	A number of sclerotic and atheromatous patches in aorta and big arteries.	Normal.	Not examined.
40 y. ♂	Idiopathic dilatation of œsophagus; beginning bronchopneumonia.	With the exception of a few sclerotic patches in arcus aortæ, normal conditions.	Slight white thickening of intima.	Not examined.
42 y. ♀	Double pleurisy; pericarditis; endocarditis; bronchitis; nephritis.	With the exception of a few sclerotic patches in aorta ascendens, everywhere normal conditions.	Slight patchy thickening of intima.	Thickening of intima slight; very dense tissue; no degeneration.
49 y. ♂	Aneurism of aorta of syphilitic origin; periœsophagitis gangrænosa; bronchopneumonia.	Mesaortitis luetica; slight atheromatous patches in many arteries.	A few atheromatous patches on the left side; nothing on the right side.	Not examined.
33 y. ♂	Endocarditis verrucosa valv. mitr.; insufficiency of the aortic valves; general stasis.	Very slight atheromatosis.	Slight whitish thickening of intima.	Not examined.
53 y. ♀	Lymphosarcoma of the pancreas; peritonitis purulenta.	Slight atheroma of the aorta.	Normal.	Not examined.
48 y. ♂	Hypertrophic cirrhosis of liver; endocarditis valv. mitr.; myocarditis.	A number of atheromatous patches in aorta and big arteries.	Slight thickening and atheroma of intima.	Not examined.
63 y. ♂	Carcinoma œsophagi with gastrostomy; bronchopneumonia; atrophic cirrhosis of liver.	Slight sclerotic and atheromatous degeneration of aorta.	Thickening of intima, also in popliteal arteries.	Thickening with some calcification of intima; in popliteal arteries same conditions; in tibiales nearly circular.
70 y. ♂	Melanosarcoma of the back with multiple metastases; tuberculous pleurisy.	Pretty severe atheromatous degeneration of aorta and big arteries.	Same as other arteries.	Not examined.
79 y. ♂	General arteriosclerosis; lues; emphysema; tuberculosis of lungs.	Severe atheromatosis of aorta and big arteries; mesaortitis luetica.	Slight sclerotic and atheromatous degeneration of intima.	Not examined.

72 y. ♂	Hæmorrhage into the brain; general arteriosclerosis.	Severe sclerosis and atheromatosis of aorta and big arteries.	Right femoral artery with white thickening of intima; within the thickened area very few atheromatous patches; in left femoral artery less changes.	Not examined.
74 y. ♀	Bronchopneumonia and purulent pleurisy.	A number of sclerotic and atheromatous patches in aorta and big arteries.	Slight sclerosis and atheromatosis.	Not examined.
7 y. ♀	Double pleurisy and peritonitis of pneumonococcic origin.	Normal.	Very slight streaks of thickening of intima.	Not examined.
40 y. ♂	Chlor-gas poisoning; multiple thrombosis of heart and arteries of lung.	Slight sclerosis and atheromatosis of the aorta.	Same as aorta.	Not examined.
65 y. ♂	Chronic endocarditis and myocarditis; general arteriosclerosis.	Severe atheroma and calcification of aorta and big arteries.	Same as other arteries.	Not examined.
68 y. ♂	Tetanus traumaticus; lobular pneumonia; fibrous myocarditis.	Slight sclerosis and atheromatosis of aorta and big arteries.	Same as other arteries.	Not examined.
48 y. ♂	Chronic glomerulo-nephritis; Dilatation of heart.	Slight sclerosis and atheromatosis of aorta and big arteries.	Same as other arteries.	Not examined.
61 y. ♂	Atrophic cirrhosis of liver; general arteriosclerosis; situs inversus totalis.	Severe atheromatosis of aorta and big arteries.	Sclerotic and atheromatous patches.	Not examined.
72 y. ♀	General arteriosclerosis; hypertrophy of heart.	Considerable atheromatous degeneration of aorta and big arteries.	Same as other arteries.	Not examined.
59 y. ♀	Peritonitis after pylorectomy for carcinoma; atrophy of internal organs.	A number of sclerotic and atheromatous patches.	Same as other arteries.	Not examined.
49 y. ♂	Duodenal ulcer; pneumonia post operationem.	Slight atheromatous degeneration of aorta and big arteries.	Same as other arteries.	Not examined.
51 y. ♂	Multiple fractures; genital atrophy; chronic arthritis of right knee.	Calcification of arcus aortæ; generally little sclerotic and atheromatous degeneration.	In *left* femoral artery slight white thickening of intima. In *right* femoral artery, no thickening.	Thickening of intima with hyaline and calculous degeneration of deep layers of intima.

TABLE—*continued.*

Age and Sex.	Pathological diagnosis.	General appearance of arteries (aorta, etc.).	Appearances of femoral arteries just beneath the ligament-Pourparti.	
			Macroscopical.	Microscopical.
84 y. ♀	General arteriosclerosis; atrophy of internal organs; Paraganglioma of left adrenal gland.	Severe sclerosis and atheromatosis of all arteries.	Same as other arteries.	Not examined.
67 y. ♀	Carcinoma of right bronchus with multiple metastases; transverse myelitis dorsalis; ascending cysto-pyelonephritis.	Slight sclerosis and atheromatosis.	Normal.	Not examined.
7 y. ♀	Diphtheria with tracheotomy.	Normal.	Normal.	Not examined.
54 y. ♂	Tuberculosis of lungs; syphilis; atrophy of heart.	Mesaortitis luetica, sclerotic and calcified patches in aorta.	Slight sclerotic and atheromatous patches.	Not examined.
48 y. ♂	Pneumonia, pleurisy and leptomeningitis of pneumococcic origin.	Slight sclerosis and atheromatosis of aorta.	Slight thickening of intima in left femoral artery.	Not examined.
16 y. ♀	Purulent peritonitis after gangrenous appendicitis.	Slight atheromatous patches in aorta.	Normal.	Not examined.
40 y. ♂	Carcinoma of gall-bladder with multiple metastases; myocarditis.	Very slight patchy atheromatosis of arcus aortæ; all the other arteries normal.	Normal.	Not examined.
4½ y. ♂	Tuberculous meningitis; miliary tuberculosis.	Normal.	Normal.	Not examined.
82 y. ♀	Carcinoma of the stomach with multiple metastases; tuberculosis of lungs.	Severe atheromatous and calculous degeneration of aorta and big arteries.	Same as other arteries.	Not examined.
0 y. ♂	Still-born child.	Normal.	Normal.	Not examined
50 y. ♂	Delirium tremens; dilatation of heart.	Slight atheromatous degeneration of aorta and big arteries.	Small atheromatous patches, no thickening.	Not examined.

70 y.	♂	Sclerosis of aortic valve; dilatation and hypertrophy of heart; atrophy of kidneys	Aorta from arcus away with only few sclerotic and atheromatous patches.	Very slight white thickening of intima, no atheromatosis.	Not examined.
55 y	♂	Carcinoma œsophagi; gangrene of lung; pleurisy.	A considerable number of sclerotic and atheromatous patches in aorta and big arteries.	Same as other arteries	Not examined.
74 y.	♂	Miliary tuberculosis.	Severe atheromatous and calculous degeneration of all big arteries.	Same as other arteries.	Not examined.
0 y.	♀	Still-born child.	Normal.	Normal.	Not examined.
56 y.	♀	Tuberculosis of lungs; pleurisy; endocarditis; thrombosis of femoral veins.	Normal.	Normal.	Not examined.
74 y.	♀	General arteriosclerosis; hæmorrhages into brain; atrophy of kidneys; endocarditis; thrombosis of pulmonal arteries.	Middle strong degeneration (atheromatous and sclerotic) of aorta and big arteries.	Same as other arteries.	Not examined.
44 y	♂	Tuberculous meningitis; tuberculosis of lungs; pleurisy; atrophy of heart.	Slight sclerosis and atheromatosis of aorta.	Slight thickening with very slight atheromatosis of intima.	Not examined.
65 y.	♂	Carcinoma of prostate with metastases in bone marrow; pneumonia; cysto-pyelitis.	A number of sclerotic and atheromatous patches in aorta.	Slight atheromatosis with sclerosis.	Not examined.
19 y.	♀	Tumor of spine with transverse myelitis; atrophia of internal organs; big decubital ulcers.	Normal.	Normal.	Not examined.
75 y.	♀	General arteriosclerosis; hypertrophy of heart.	Severe sclerosis and atheromatosis of aorta and big vessels.	Same as other vessels.	Not examined.
5½ y.	♂	Appendisectomy; lobar pneumonia; fatty degeneration of liver.	Normal.	Normal.	Not examined.
48 y.	♀	Carcinoma cervicis uteri; fistula recto-vagino-vesicalis; cysto-pyelo-nephritis.	Very slight sclerosis and atheromatosis of aorta.	Normal.	Not examined

TABLE—*continued.*

Age and Sex.	Pathological diagnosis.	General appearance of arteries (aorta, etc.).	Appearances of femoral arteries just beneath the ligament-Pourparti.	
			Macroscopical.	Microscopical.
73 y. ♀	Nephrolithiasis on both sides.	Severe sclerosis and atheromatosis of aorta and big arteries.	Slight sclerosis and atheromatosis.	Not examined.
50 y. ♀	Carcinoma of the gall-bladder with metastases in liver, ovaries and peritonæum.	Slight sclerosis and atheromatosis of aorta.	Normal.	Not examined.
61 y. ♂	Tuberculosis of lungs and intestine; pleurisy.	Slight sclerosis and atheromatosis of aorta.	Normal.	Not examined.
18 y. ♀	Glioma of the brain; hydrocephalus internus.	Very slight sclerosis and atheromatosis of aorta at site of branching off of intercostal arteries.	Normal.	Not examined.
66 y. ♀	Infarctus of lungs; lobular pneumonia; endocarditis of mitral and aortic valves; pleurisy; meningitis.	Slight sclerosis and atheromatosis of aorta and big arteries.	Slight whitish thickening of intima.	Not examined.
49 y. ♂	Bright's disease; hypertrophy of heart; multiple infarctus of lungs.	A number of sclerotic and atheromatous plaques in aorta and big arteries.	Same as other arteries.	Not examined.
62 y. ♂	General arteriosclerosis; hypertrophy of heart.	Severe sclerosis and atheromatosis of aorta and big arteries.	Same as other arteries.	Not examined.
73 y. ♀	Pernicious anæmia; hydrothorax; atrophy of heart; emphysema of lungs.	Very small numerous patches of sclerotic and atheromatous nature in aorta and big arteries.	Same as other arteries.	Not examined.

of quite normal structure elsewhere, showing no fatty degeneration, no formation of clumps in its central parts, as do the other elastic elements within the intima. The deep longitudinal muscle fibres of the intima are in the slight cases in a fairly good condition, forming a compact layer which is thickest at the origin of lateral branches. The fibrous tissue of the intima is in every case of somewhat different thickness. In the slight cases it scarcely reaches the thickness of the media ; in the severe cases it may measure 2-3 mm. in its central part. The fibrous tissue is nearly always dense, contains few cellular elements and presents great variations in the degree of degenerative change. In many cases, even an intima of 1 mm. thickness shows no signs of fatty or calcareous degeneration at all. The connective tissue fibres are thick, homogenous, quite regular from the base of the thickening to its surface. In other cases there is considerable degeneration with smaller or bigger drops of fat, both in the elastic elements and in the deep layers of connective tissue, in other cases there is beginning calcareous degeneration, in others the intimal thickening is detached, not only in the lateral part, but also under the centre, from the underlying media, which in these cases is often in a very atrophic condition. The spaces formed in this way may be filled with blood, which has penetrated from the inside of the artery. In such cases, similar and even more advanced sequels of repeated partial lateral detachment of the intimal thickening from the underlying wall may be noticed. Two or three layers of newly-formed connective tissue, separated and recognizable by the elastic elements at the base of each layer, which have been ruptured and the ends of which on the side of the intimal thickening are turned towards the arterial lumen or even (probably by the bloodstream) are wholly turned back to form a half-circle towards the side they came from, may be seen. The irregularities thus formed are filled up with connective tissue. Later on, a new rupture may happen, and so on. The intimal thickening never shows signs of inflammation : there are no vessels, leucocytes, etc., in it. The media in the slight cases is not noticeably changed. The Dürck's " Gitterfasern " as well as the other elastic elements and the muscle fibres are not degenerated. The media is at first neither thicker nor thinner. Later on, as the intimal thickening increases, the media becomes thinner in varying degree. In our first described case the thickness of the media under the very considerable intimal thickening was still about half the thickness of the media under the normal intima. On the other hand we found cases of less severe thickening with such a reduced media that for a short way it disappeared. In conspicuous cases the media shows changes similar to those described in our first case. The degenerative lesions are sometimes more pronounced, vasa vasorum may have formed, lymphocytes and calcification of the media may be observed. The adventitia is unchanged.

It appears that the degenerative changes (fatty degeneration, calcification) are always of a secondary nature. It is true that in some

slight cases of intimal thickening we found a considerable number of the elastic elements of the hyperplastic elastic layer involved in a more or less pronounced fatty degeneration ; but that is not always the case, and when it happens, it is not uniform. Sometimes we find fatty degeneration (in these cases more in the connective tissue cells than in the elastic fibres) where there is scarcely any intimal thickening. We are therefore convinced that the first cause of the lesion is not a degeneration, but an overstrain of the elastic elements at the base of the intima. The constant pressure of the bloodstream against the posterior wall of the external iliac and upper femoral artery when the leg is bent at the hip joint, or the mechanical strain of stretching by movements of the leg, may separately produce this strain or they may work simultaneously. The fact that in the right iliac artery of our first case there were two fibrous bands, the upper situated near the origin of the internal iliac artery, at some distance from the hip joint, would speak in favour of the first possibility. On the other hand we cannot explain the detachment of a border of the thickening, with rupture and turning of the elastic elements towards the lumen, except by assuming the trauma to be caused by the movement of the hip. It is quite possible that the severe alterations in our first case were connected with the occupation of the patient, who, being stationmaster, had to climb a great deal up and down waggons.

At any rate we cannot admit explanations other than mechanical. That secondary degenerations are apt to occur is natural. The reasons are multiple. Admitting a mechanical lesion of the elastic elements, the intimal thickening is of a protective nature. Why does this thickening only occur in a certain, though considerable, number of cases, but not in all ? And why are the degrees of thickening and the length of the band so unequal ? The traumatic strain varies according to the different conditions of life. Age plays also a certain role, prolonging the duration of strain ; though we have found femoral arteries with fibrous intimæ in young subjects and have found, on the other hand, femoral arteries with no visible thickening in advanced age, especially in women.

In one of our cases, a man who had a chronic arthritis of the right knee, the right leg was apparently used less than the left, which was normal. The post-mortem (he died suddenly from a fracture of the skull) disclosed no thickening on the right side, but a distinct though slight thickening in the left upper femoral artery.

But the difference of traumatic strain is probably insufficient to explain all the varieties.

The mass of bloodless fibrous tissue is of course easily prone to degenerate (hyaline, fatty, calcareous), as also is the compressed media under this

thickening. In arteriosclerosis we usually have two series of changes: degenerative and regenerative, but which is primary we cannot discuss. Arteriosclerosis is supposed by some to be toxic, by some to be mechanical in origin; the question is still undecided.

Our cases of intimal thickening are of mechanical origin. It is probable that, just as a certain degree of intimal thickening (by formation of a hypertrophic elastico-muscular layer) near the origin of intercostal and other arteries in the aorta is a normal happening of nature life, also a certain amount of intimal thickening in the femoral artery is not necessarily pathological, but only a physiological reaction of the artery to increased strain in this situation. The thickening becomes pathological as soon as the formation of fibrous tissue exceeds considerably the elastic elements and when the latter show the later degenerative changes.

Under such conditions it seems justifiable to call these pathological intimal thickenings sclerosis of the femoral and external iliac artery. Atheromatosis does not frequently accompany these sclerotic changes; and that is a notable difference between our cases and those of ordinary arteriosclerosis.

Here we must refer to a publication by Oberndorfer, who studies the limitation of arteriosclerosis to certain arteries (especially in the vertebral, femoral and popliteal arteries) in some cases, and who finds that the arteriosclerosis is most advanced (and combined with calcification) where the artery is not exposed to the movement of a neighbouring joint, whilst where the artery passes near a joint, the wall remains soft. We agree generally with the statement of Oberndorfer, but our results complete his observations, in that we can say that near the hip joint ordinary arteriosclerosis in an advanced condition is infrequent, but usually a fibrous intimal thickening which does not cause the risk of rupture of the whole arterial wall, as would be the case were the artery calcified. The absence of severe degenerative changes in most of our cases may be due, as Oberndorfer points out for his cases, to the natural massage and increased circulation of fluid in the arterial wall caused by the constant movements of the hip joint. Here we may also remember that, according to Hallenberger and others, sclerosis of the radial artery, an artery which has to submit to much longitudinal tension through movements of the neighbouring joints, is usually of the fibrous type and shows generally little, if any, atheromatosis.

Our cases throw light upon the production of arteriosclerosis by mechanical factors, and especially upon the influence of such factors upon the elastic elements of the intima. In contradistinction to Barach, we did not find a primary change in the media, therefore this change is secondary, the primary being in the intima.

Finally we are led, from a consideration of our cases, to plead for a clearer distinction between the cause of sclerosis and of atheromatosis of the arteries.

It may be that, according to the theory of Jores, Aschoff, and others, the intimal thickening is generally the objective sign of a physiological or pathologically increased mechanical strain (increased blood-pressure, movements of the bloodstream, constant movements of arteries passing near joints, etc.), whilst the degenerative changes, which can happen with, or without, considerable primary thickening, may be due to poisoning or malnutrition, either general, as in the case of arteriosclerosis in young subjects with tuberculosis and other infective diseases, or local. The damaged regions are those on which cholesterinester or lipoids are deposited.

If we subdivide the chapter of arteriosclerosis into those of hyperplasia and degeneration, we have no longer the need to make a qualitative distinction between our keloid-like intimal thickening of the femoral artery and the hyperplastic form of arteriosclerosis.

As regards the endarteritis obliterans of Winiwarter, both his description and the description of similar cases by other authors differ so much from that of our intimal thickening, that it seems unnecessary to discuss the question of a relation between the two lesions.

AFTER EFFECTS OF EXERCISE ON PULSE RATE AND SYSTOLIC BLOOD PRESSURE IN CASES OF "IRRITABLE HEART."*

By T. F. COTTON, D. L. RAPPORT and THOMAS LEWIS.

(*From the Military Hospital, Hampstead.*)

THE objects of the present observations were several. Firstly, to obtain by repeated observations upon a relatively small number of patients† and controls, accurate curves of the pulse and blood pressure changes following immediately upon the termination of exercise. Secondly, to compare these curves in patients and controls with a view to determining qualitative and quantitive differences. Thirdly, to grade the amount of work performed, and to study and compare the consequent variations in the curves of patients and controls. Fourthly, to ascertain the relations, if such exist, between the changes in pulse and systolic pressure and the symptoms resulting from exercise.

The subjects investigated lift 20-lb. dumb-bells from the floor to the full stretch of the arms above the head, swinging them in one motion up and in one motion down, the complete movement occupying 2, 3, 4 or more seconds (guided by metronome). The movement is repeated a number of times (7-60) according to the capacity of the subject ; the rate of movement is varied for the same reason. The controls and patients perform, after preliminary tests, a chosen series of these exercises, graded in simple arithmetic ratios ; the stiffest exercise being sufficiently short of the maximal effort to avoid ill effects, but enough to induce distress of breathing and fatigue.

In general each subject performs two series of exercises, in one of which the number of lifts is increased, the rate of work remaining constant ; in the other of which the number of lifts remains constant, the rate of work being increased. Each individual exercise is performed on three occasions, each separated by a day or more, and the three curves of pulse rate and blood pressure so obtained (Fig. 1) are used to construct average curves, of which the remaining curves here published are examples.

* Work undertaken on behalf of the Royal Medical Research Committee.

† The patients were soldiers complaining of several of the following symptoms : breathlessness, pain, giddiness, palpitation and exhaustion upon exertion ; in none was there a physical sign of structural change in the heart.

The blood pressures are taken by means of Martin's Riva-Rocci sphygmomanometer, and pulse rates are taken from the other brachial vessel by means of a similar armlet communicating by air pressure with an Erlanger capsule which in turn moves a polygraph tambour. By a system of tubes and taps, connected to a pressure bottle (for the details of which see the forthcoming paper of Rapport, in the Archives of internal Medicine), the two armlets which are in place during the accomplishment of the work can be inflated at the moment exercise ceases

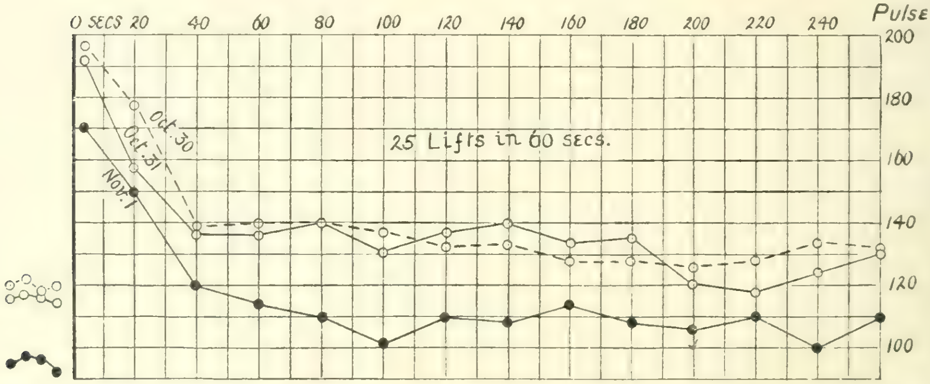


Fig. 1. Curves of pulse rate from a patient suffering from irritable heart. Three curves, with the preliminary or control readings are shown. They were taken on successive days. In this instance there is a clear relation between the preliminary pulse rate and the rate after exercise (25 lifts in about 60 seconds in each instance); this relation is usually absent.

Each single curve in the subsequent illustrations was constructed by averaging the curves shown on charts of this kind. The zero line in this and all subsequent charts representing the end of exercise.

and very early readings are then obtained of pulse rate and blood pressure. The later readings are written on the continuous pulse curve and their relations to other events accurately recorded in point of time. A number of preliminary readings (Fig. 1) are taken before each exercise, which is delayed until such readings are uniform and at the level determined as the resting levels for the subject. All the observations were made upon subjects resting in an easy sitting posture.

Normal curves of systolic blood pressure. The curves of blood pressure following the termination of exercise such as we employ (*i.e.*, 10, 20, 30, 40 or 60 lifts in double the number of seconds) are illustrated by Fig. 2. The first reading, taken from 3-10 seconds after the end of exercise, is at a variable height, but not greatly above normal resting pressure. The curve rises steeply from this point and in from 20-60 seconds reaches a maximum from which it falls away gradually to normal in from 1 to 4½ minutes from the end of exercise. This initial rise in the curve is invariable, being independent of the amount of work and of the rate at which it is accomplished,

within the limits of our tests. According to our view it is brought about in the following fashion. During exercise and while the trunk and bells are lifted the musculature of the body is tense, and blood is driven from the

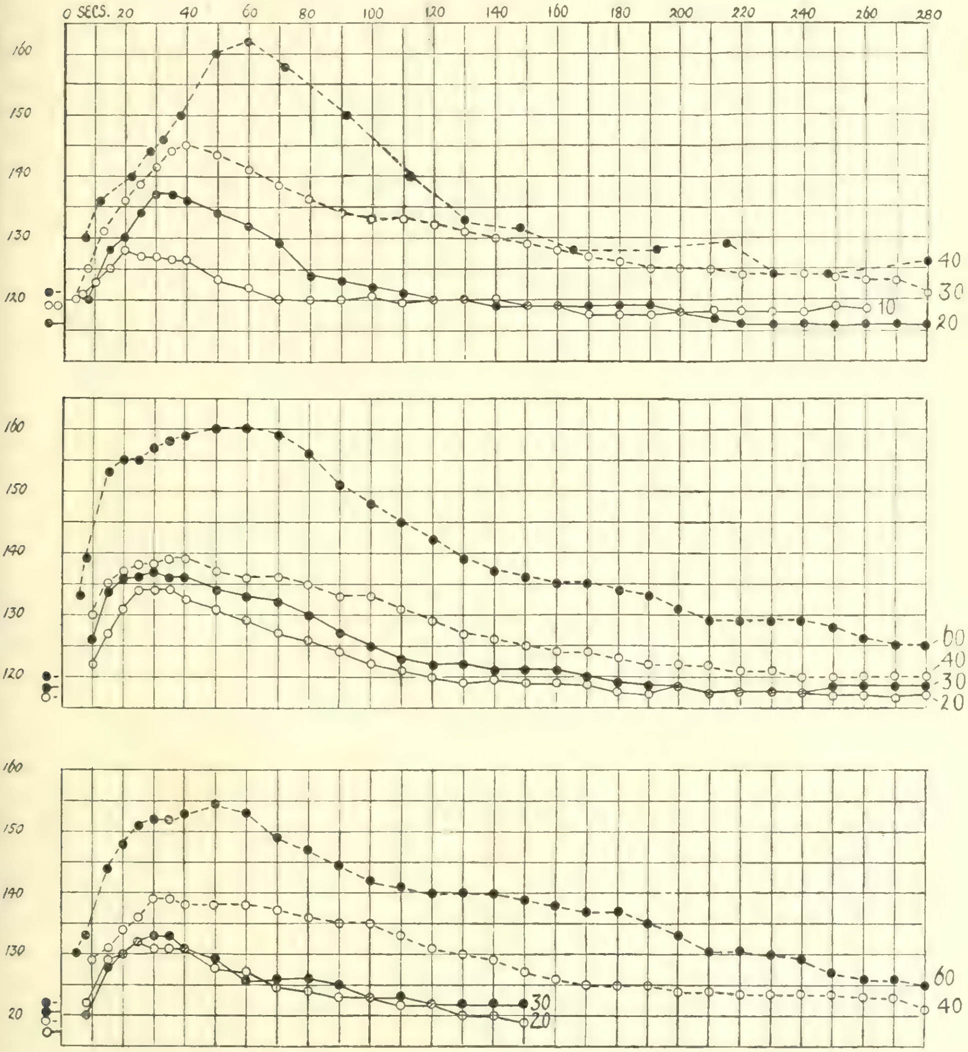


Fig. 2. Three charts from healthy individuals. Each chart shows the averaged curves for the corresponding subject following a series of exercises in which the rate of work was constant (1 lift in 2 seconds) but in which the number of lifts was increased. The number of lifts is shown to the right against each average curve.

veins into the arteries. The venous reservoirs of the abdomen, as well as those of the limbs, are partially depleted. This transference of blood to the arterial system produces with other factors, such as increased rate and

power of heart action and increased tone of the arterial wall, a high systolic blood pressure. Immediately at the end of exercise the subject sits and rests, the muscles relax, the depleted veins take up the blood flowing out

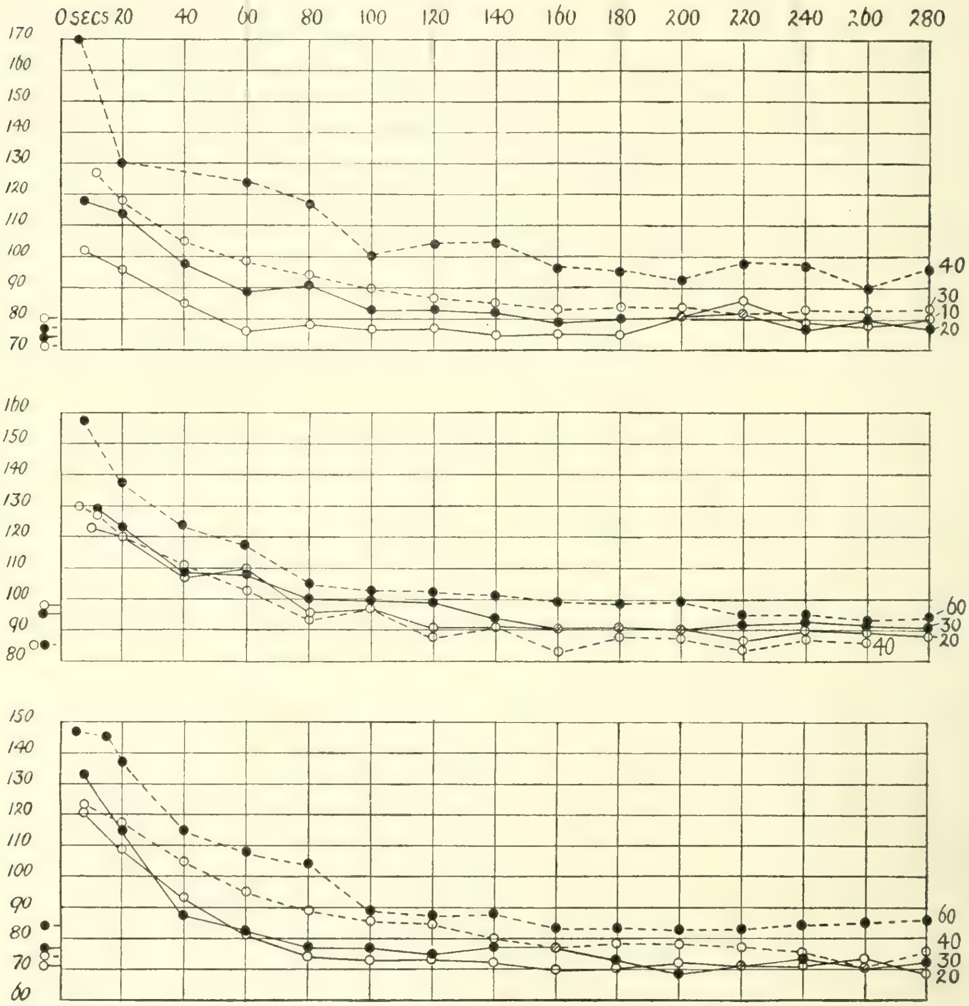


Fig. 3. Three charts of averaged pulse curves. The curves correspond to the series of blood pressure curves of Fig. 2.

from the capillaries; the heart is momentarily robbed of its supply; a steep fall of arterial pressure occurs and the pressure remains reduced until the veins fill and overflow. This overflow, by feeding the heart, produces

the rise of arterial pressure described.* The extent of the original fall is uncertain for the very earliest readings are not obtainable, but it is certain that sometimes in normal subjects the fall is below the original resting level; it is also probable that it always falls to a level which at the highest is not far above the original resting level. We regard the subsequent rise as a recovery to the level which the systolic pressure would assume were this mechanical factor, depletion of the veins, in abeyance; the rise is, according to this view, a continuation of the raised pressure of exercise, in so far as the latter is due to factors other than emptying of the veins into the arteries (*i.e.*, that portion of it which is due to augmentation of the heart's action and to increased tone of the arterial vessel wall).

Supporting this hypothesis is an observation devised to test it. If at the termination of exercise the subject, instead of sitting with the elbows on his knees (usual posture), stands, the external pressure on the abdominal veins is less; moreover, the static pressure in the veins of the legs is increased. Both these circumstances add to the potential reservoir created at the moment effort ceases. The result is a more profound fall of pressure, a fall which is deeper and more prolonged. A fairly typical example of the two curves, one taken in the sitting (white) the other in the standing position (black) is shown in Fig. 4. It is one of a number of examples which we possess. The first reading is 10 mm. lower in the curve taken standing and the rise is more prolonged. In some instances the initial lowering of pressure is sufficient to produce giddiness, and the first reading may then be taken well below normal. The maximum reading is always less in the standing than in the sitting posture (usually there is a greater difference than is to be seen in this figure), a difference which is to be attributed chiefly to the static factor of posture; systolic blood pressure in the arm is recognised as being lower for the standing than for the sitting posture.

Variations in the curves with increased effort. The test exercises have been graded in severity by varying the amount of work and by varying the rate of work. If the work is increased, but a constant rate of work is maintained, the rise of pressure is increased, the summit of maximal pressure is delayed and the rise is prolonged (Fig. 2). Such are the events when the exercises are such as we employ; it should be emphasised that these are exercises in which the limit of endurance is reached within a few minutes. Exceptionally the increments of rise are nicely proportioned to the actual amount of work done (Fig. 2, top chart). Usually the increments of rise

* The curves are similar to those found in Valsalva's experiment. In this the end of violent expiration with the glottis closed is followed by a steep fall of systolic pressure. During the expiration blood is forced from the abdomen and chest, in both of which cavities the pressure is raised by some 50 or more mm. of Hg. through the muscular effort. At the moment of relaxation, a potential but unfilled reservoir exists in the veins, the filling of these veins depletes the heart and lowers pressure which recovers and passes the normal as the veins become filled as explained by Lewis, *Journal of Physiol.*, 1906, xxxiv, 391. *Note.*—The explanation given by Lewis of the fall is probably correct. His explanation of the subsequent rise is certainly incorrect.

TABLE I.

Subject. Controls.	Work. Lifts (20-lb. bells).	Work. Duration in secs.	Pulse. Before exercise.	Pulse. After exercise. Immed or max. reading	Pulse. After exercise. Rise.	Pulse. After exercise. Fall to normal in secs†	Systolic blood pressure. Before exercise.	S.B.P. After exercise. 1st reading.	S.B.P. After exercise. Max. reading.	S.B.P. After exercise. Time of max. in secs.	S.B.P. After exercise. Rise.	S.B.P. After exercise. Fall to normal in secs‡	Remarks.
C.	40	80	78	170	92	280+	121	130	162	60	41	230	Considerably breathless: very fatigued: palpitation.
Weight 154 lbs.*	30	60	72	127+	55+	280+	119	120	145	40	26	220	Breathless, slight fatigue.
Height 70 in.*	20	40	74	118	44	160	116	120	137	33	21	120	Slight breathlessness.
	10	20	80	112	32	60	119	121	128	20	9	50	Slight breathlessness.
L.	60	120	85	158	73	280+	120	133	160	55	40	270	Considerably breathless, fatigue, palpitation.
Weight 147 lbs.	40	80	85	130	45	120	117	130	139	40	22	210	Some breathlessness.
Height 72 in.	30	60	95	130+	35+	100	118	126	137	30	19	110	Slight breathlessness.
	20	40	98	123	25	80	116	122	134	30	18	110	Slight breathlessness.
R.	60	120	84	147	63	120	122	130	154	50	32	250	Considerably breathless, giddy, fatigue.
Weight 126 lbs	40	80	74	123	49	160	120	129	139	32	19	170	Some breathlessness.
Height 68 in.	30	60	77	133	56	80	121	120	133	32	12	60	Slight breathlessness.
	20	40	71	120	49	80	117	122	132	25	15	90	Slight breathlessness.
R.	40	77	72	136	64	160	119	139	145	28	26	220	Breathless, some fatigue.
Weight 126 lbs.	40	118	70	122	52	120	117	132	139	22	22	190	Slight breathlessness.
Height 68 in.	40	157	72	110	38	120	117	124	134	22	17	190	No symptoms.
C.	40	80	81	155	74	280+	115	129	151	60	36	200	Considerably breathless, slight fatigue.
Weight 154 lbs.	40	120	86	143	57	160	113	124	140	50	27	150	
Height 70 in.	40	163	85	121	36	100	113	122	131	30	18	110	
	Stairs												
C.	90	18	74	130	56	280+	120	134	150	45	30	230	Breathless, no fatigue, palpitation.
Weight 154 lbs.	90	26	75	118	43	140	120	141	145	40	25	210	Breathless, no fatigue.
Height 70 in.	90	53	75	110	35	60	120	136	146	25	26	120	Very slight breathlessness.
	90	103	77	101	24	40	124	142	148	20	24	130	Pulse dropped below normal. No symptoms.
	45	52	77	96	19	40	120	128	134	22	14	80	Pulse dropped below normal. Very slight breathlessness.
R.	90	17	68	139	71	280+	124	142	149	35	25	250	Breathless.
Weight 126 lbs.	90	55	72	107	35	60	120	134	138	28	18	190	Pulse dropped below normal. Very slight breathlessness.
Height 68 in.	90	110	70	95	25	40	122	129	139	22	17	140	Pulse dropped below normal. No symptoms.
	45	53	70	95	25	40	123	123	130	35	7	50	Pulse dropped below normal. Very slight breathlessness.

* Weight of patient and height of lift.
† Approximate time taken for pulse to first reach a point within 5 beats of normal.
‡ Approximate time taken for S. B. P. to first reach a point within 5 mm. of normal.

SUBJECT. PATIENTS.	WORK. Lifts (20 lb. bells).	WORK. Duration of in secs.	PULSE. Before exercise.	PULSE. After exercise. Or max. reading.	PULSE. After exercise. Rise.	PULSE. After exercise. Fall to normal in secs†	SYSTOLIC BLOOD PRESSURE. Before exercise.	S.B.P. After exercise. 1st reading.	S.B.P. After exercise. Max. reading.	S.B.P. After exercise. Time of max. in secs.	S.B.P. After exercise. Rise.	S.B.P. After exercise. Fall to normal in secs‡	REMARKS.
1. C.	30	62	81	158	77	280+	124	149	182	50	58	280+	Considerably breathless, fatigue.
Weight 131 lbs.*	20	42	87	153	66	180	125	144	165	38	40	180	Breathless
Height 77 in.*	10	21	87	138	51	60	123	135	154	30	31	210	Not breathless.
	25	52	92	159	67	240	125	136	176	35	51	260+	Considerably breathless, fatigue.
	25	77	84	148	64	280+	125	146	164	30	39	210	Breathless.
	25	98	84	129	45	240	125	135	163	25	38	250	Not breathless.
2. B.	30	63	77	146	69	80—	118	145	160	33	42	250	Pulse falls below normal. Considerably breathless, fatigue.
Weight 128 lbs.	20	39	84	136	52	60—	115	143	158	25	43	220	Breathless.
Height 79 in.	10	20	85	127	42	40	116	131	148	23	32	170	Not breathless
	25	53	87	156	69	60	119	144	158	55	39	200	Breathless.
	25	73	85	146	61	80—	118	137	159	30	41	210	Slight breathlessness.
	25	97	89	143	54	60	116	140	158	30	42	210	Not breathless
3. Cl.	24	70	83	168	85	140	115	141	157	35	42	220	Pulse falls below normal. Breathless.
Weight 152 lbs.	18	55	84	144	60	60—	117	137	150	30	33	180	Very slight breathlessness.
Height 79 in.	12	36	86	131	45	40	116	136	143	25	27	150	Not breathless.
	20	60	83	154	71	80—	112	133	144	32	32	190	Breathless.
	20	89	84	135	51	40	112	132	144	30	32	120	Not breathless.
	20	119	84	123	39	40	111	134	143	15	32	140	Not breathless.
4. P.	15	48	99	140	41	120	139	156	182	32	43	180	Breathless.
Weight 152 lbs.	15	60	95	130	35	120	138	147	181	30	43	210	Slight breathlessness.
Height 75 in.	15	87	97	120	23	60	139	165	175	20	36	120	Not breathless.
5. H.	20	61	114	162	48	260+	128	139	159	30	31	180	Intermittent pain, breathless.
Weight 126 lbs.	15	46	110	143	33	260+	126	145	153	30	27	120	Slight breathlessness, intermittent pain.
Height 73 in.	10	30	115	147	32	260+	123	137	147	32	24	150	Not breathless, intermittent pain.
	15	31	107	154	47	280+	122	140	148	35	26	170	Breathless, pain.
	15	45	111	145	34	160	124	142	144	27	20	140	Preliminary fall of S. B. P. (4 mm.). Very slight breathlessness, pain.
	15	61	103	145	42	280+	124	146	146	6	24	150	Not breathless, pain.
6. He.	20	61	101	157	56	260+	118	150	158	30	40	170	Prelim. pulse rise 5. Prelim. fall of S.B.P. 2mm. Breathless, fatigue.
Weight 140 lbs.	15	46	96	157	61	260+	117	145	150	40	33	160	Prelim. pulse rise 15. Prelim. fall of S.B.P. 6mm. Slight breathlessness.
Height 77 in.	10	31	95	142	47	240	117	140	143	35	26	130	Prelim. pulse rise 10. Prelim. fall of S.B.P. 3mm. Not breathless.
	15	46	119	174	55	280+	129	139	158	32	29	240	Considerably breathless, fatigue.
	15	60	114	169	55	280+	125	145	154	23	29	120	Preliminary pulse rise (4). Breathless.
7. J.	15	60	82	149	67	140	128	153	163	32	35	180	Considerably breathless, giddy, fatigue.
Weight 145 lbs.	11	45	84	129	45	80	126	145	163	32	37	160	Preliminary pulse rise (19). Breathless.
Height 72 in.	7	28	79	107	28	40	126	140	161	30	36	190	Preliminary pulse rise (5). Slightly breathless
	12	36	84	149	65	60	127	159	168	30	41	170	Pulse fell below normal. Considerably breathless, fatigue.
	12	55	78	121	43	60	126	153	161	25	39	200	Preliminary pulse rise (2). Breathless.
	12	72	81	118	37	40	128	158	165	20	33	160	Preliminary pulse rise (5). Breathless.

NOTE.—Patients 1 and 2 were chosen for their relative fitness; patients, 3, 4, and 5 were average cases; 5, 6 and 7 were chosen for the severity of their maladies.

* Weight of patient and height of lift.

† Approximate time taken for pulse to first reach a point within 5 beats of normal.

‡ Approximate time taken for S. B. P. to first reach a point within 5 mm. of normal.

are small until the full effort is approached, and the final rise is an exaggerated one (Fig. 2, middle chart).

If the amount of work is kept constant but the rate of work is increased the changes are similar. It is the rule to observe an increased rise, a delayed summit, and a rise which is prolonged. But the increments of rise are slighter than is the case when the work is increased. In some instances they are absent ; we have noticed this especially when the test has been the more accustomed effort of stair climbing (see latter part of Table I).

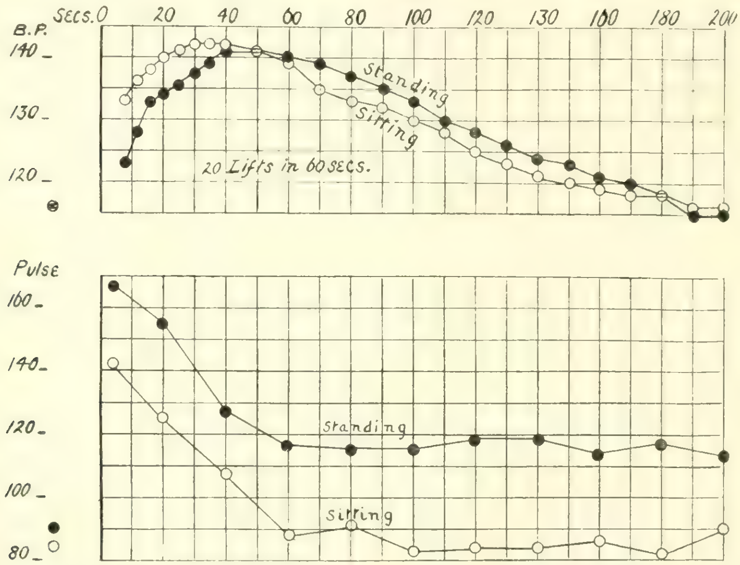


Fig. 4. Averaged blood pressure and pulse rate curves following exercise. The preliminary readings were all taken in the sitting posture. The curves marked by plain circles represent the B. P. and P. R. after exercise, with the patient sitting and resting with the elbows on the knees ; the curves marked in black are the corresponding curves, with the patient standing after the last lift.

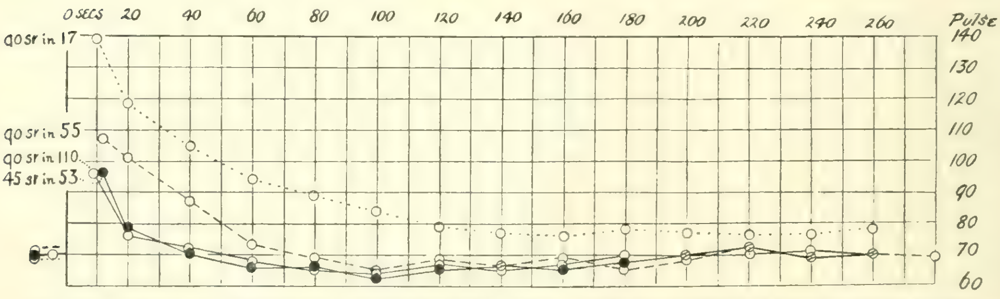


Fig. 5. Averaged curves from a normal subject, showing the after effects of stair climbing on the pulse rate. The number of stairs climbed and the number of seconds occupied by the climb are given to the left. In this instance, the maximal pulse rate attained was increased when the rate of work was increased, but not when the amount of work was increased.

Normal curves of pulse rate.

In form these curves are relatively simple. The pulse rate is invariably highest at the cessation of exercise and declines, at first rapidly, then more gradually, until the normal rate is reached or passed.

If the amount of work is kept constant and rate of work is increased, the maximal pulse rate varies correspondingly (Fig. 5); it increases by fairly uniform increments, though the last increment, as full effort is approached, is often exaggerated. The duration of the rise is also increased.

If the amount of work is increased and the rate of work is kept constant the changes lack uniformity. There is the general tendency for the rise of pulse to be greater with the greater effort, and some series of curves show uniformity in this respect (see Fig. 2, top chart), but it is as usual, if not more usual, to find no material change in the rates until the full effort is approached (see Fig. 2, middle chart, and also Fig. 5).

Within certain limits of effort it may be said that the blood pressure rises are controlled more by the actual amount of work done, the pulse rate more by the rate at which work is accomplished. While this statement is true, we are unable to formulate a more definite rule that the blood pressure rise is constant for a given *amount* of work, the pulse rate rise for a given *rate* of work.

Blood pressure and pulse curves in patients.

With the exception of certain curves presently to be described it may be said that so far as the general form is concerned, the curves of patients and control are identical. Such differences as exist are quantitive and not qualitative.

The effects of exercise in healthy subjects and patients may be compared from two standpoints. We may compare the effects of a given amount of work, the lifting of a given weight through a given distance and in a specified time. Secondly, we may compare the circulatory changes called forth in control and patient by effort so graded as to produce in each similar objective evidences of distress. Each method has its value.

The effects of fixed tests. Healthy young adults, untrained to the work, will lift the 20-lb. bells 40 to 60 times in double the number of seconds before approaching the full effort. The pulse rises to 150 or 170, the systolic pressure to 155 or 160. None of our patients are capable of such effort; equal distress and similar pulse rates and systolic pressures are produced by smaller amounts of work or work done more slowly. It is clear that if we

chose a given amount of work as a stimulus and apply this stimulus to healthy controls and to our patients, the latter react to this stimulus in an exaggerated fashion. The pulse rate rises much higher than in controls, and the high rate is longer sustained, the blood pressure rises higher and the raised pressure is longer sustained than in controls ; the summit of the blood pressure is not delayed, however ; breathlessness, fatigue, and palpitation are also much more in evidence (Figs. 6 and 7, and Table II). So far as the pulse is concerned the examples given in the accompanying Tables I, II, III, and many which are to be found in contemporary papers will suffice. Additional evidence has been collected in regard to

TABLE III.

Comparison of three controls and the two best patients.

(Work consisting of 30 lifts in 60 seconds.)

—	Pulse rate.			Duration of rise in secs.	S. B. P.			Time of max. in secs.	Duration of rise in secs.
	Before.	After.	Rise.		Before.	After.	Rise.		
Controls									
C.	72	127+	55	280+	119	145	26	40	220
L.	95	130+	35	100+	118	137	19	30	110
R.	77	133	56	80	121	133	12	32	60
Patients.									
C.	81	158	77	280+	124	182	58	50	280+
B.	77	146	69	80—	118	150	42	33	250

Comparison of three controls and three patients.

(Controls lifting 20 times in 40 seconds, the patients 20 times in 60 seconds.)

Controls.									
C.	74	118	44	160	116	137	21	33	120
L.	98	123	25	80	116	134	18	30	110
R.	71	120	49	80	117	132	15	25	90
Patients.									
Cl.	83	154	71	80—	112	144	32	32	190
Hi.	114	162	48	260+	128	159	31	30	180
He.	101	157	56	260+	118	158	40	30	170

blood pressure by Major Meakins and Captain Gunson, whose results are summarised in Table IV, for which we are indebted to them. This table compares the effects on systolic blood pressure of walking smartly up a single flight of 30 steps (the first reading being taken at or about a half-minute

TABLE IV.

AVERAGE SYSTOLIC BLOOD PRESSURE.

	Orig. press.	Max. press.	Duration of rise in secs.
10 Controls	129	160	12
13 patients without symptoms	125	155	18
13 patients with symptoms ..	125	172	24
7 patients with more symptoms	135	176	50

after the termination of exercise) in (*a*) 10 controls, (*b*) 13 patients who exhibited no symptoms upon the test, (*c*) 13 exhibiting some breathlessness, and (*d*) 7 exhibiting considerable breathlessness and some fatigue.

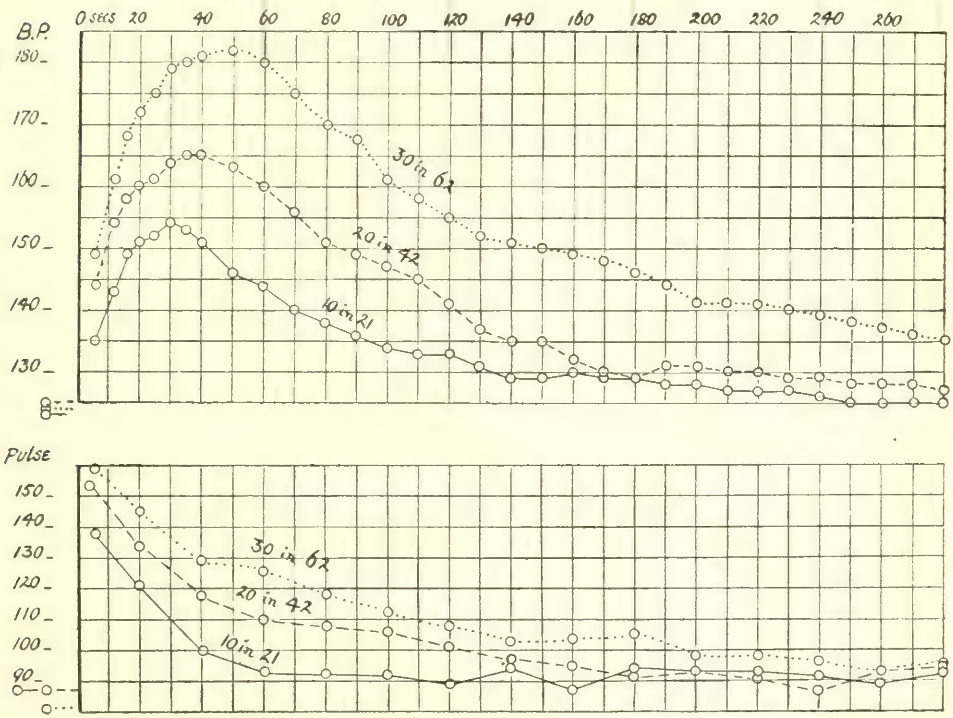


Fig. 6. Averaged curves of B. P. and P. R. for a series of exercises, in which the amount of work was increased, the rate of work remaining constant. From a patient suffering from a mild form of "irritable heart."

The effects of the stiffest tests employed. The stiffest tests are so arranged as to produce definite signs of distress and so far as possible signs of equal distress in the subjects who submit to them ; the effort is sufficient to produce considerable breathlessness and signs of fatigue, and in some the added subjective symptoms of palpitation, giddiness, precordial pain and headache. In choosing our patients we deliberately avoid those in whom the amount of exercise is limited by symptoms other than breathlessness and fatigue. In controls the pulse rate immediately after cessation of the effort producing such symptoms is found on the average to reach 158 per minute, the actual rise being some 76 beats per minute. In the patients as a complete group, the rate reaches averages 154 per minute, the actual rise being 63 beats per minute (Table V). If the patients' curves are separated into two groups, according to whether the original pulse rate is above or below 90, then similar relations are observed. In those in which the original rate is below 90 (av. 81), the pulse reaches 155 per minute, the rise being 74 beats per minute ; while in those in which the original rate is above 90 (av. 105), the maximal rate is found to be 153 beats per minute and the rise only 48 beats per minute.

TABLE V.

STIFFEST TEST.

Subject.	Pulse.			Blood pressure.		
	Orig.	Max.	Rise	Orig.	Max.	Rise.
C.	78	170	92	121	162	41
L.	85	158	73	120	160	40
R.	84	147	63	122	154	32
Control average	82	158	76	121	159	38
Ca.	81	158	77	124	182	58
B.	77	146	69	118	160	42
Cl.	83	168	85	115	157	42
P.	99	140	41	139	182	43
Hi.	114	162	48	128	159	31
He.	101	157	56	118	158	40
J.	82	149	67	128	163	35
Patients' average	91	154	63	124	166	41

The effects of effort approaching the full effort is very similar in controls and patients so far as the actual pulse rate reached is concerned. On the other hand the actual rise of rate is greater in controls (76 beats) than in patients (63 beats), for in the former class it starts at a lower level.

A relation between the original rate and the maximal rate reached cannot be established when the subjects are treated collectively. Neither is a uniform relation to be seen when the subjects are considered individually. Exceptionally (Fig. 1) the height reached bears a uniform relation to the original rate, but usually such a relation is not found. Neither is this remarkable, if it is assumed that the original rate, when raised, is raised by influences acting in the same fashion as the exercise itself. The circulation is capable at a given moment of a certain response to a given effort; it appears to be a matter of indifference whether this response has been called forth to some extent before the chief stimulus is applied providing it is called forth through similar channels.

It may be stated that for a given grade of distress (*i.e.*, that which is produced by an effort approaching the full) the pulse reaches the same level in patient and control. While we may conclude that effort which produces a certain grade of objective distress produces in patient and control a like reading of heart rate, we may not conclude that the breathlessness or the exhaustion is dependent upon this reaction of heart rate. They are not directly related. The signs of distress and the height reached by the pulse do not run hand in hand in the same individual on tests of different severity. This lack of relation where the pulse rate is concerned is often conspicuous in exercises in which the amount of work is increased, the rate of work being maintained constant. The degree of breathlessness and exhaustion produced is proportioned to the work done in these circumstances, yet the height to which the pulse rate rises may show negligible differences (see Fig. 3, middle curve). This statement applies (as may be seen in the tables) to both controls and to patients. There is often a similar lack of direct relation between distress and blood pressure rise, notably when the amount of work is kept constant but the rate of work is increased (Fig. 7, two lowest curves); often in these circumstances the blood pressure rises are almost equal, but the degree of distress always increases. The same lack of direct relation is observed when the reaction to work of different types is compared. Stair climbing, which drives the systolic pressure to a certain height, is less productive of symptoms than is weight lifting, which produces an equal blood pressure reaction in those unaccustomed to it.

The changes which occur in the rise of pressure and of pulse rate when the work is increased or when its rate is increased are similar in patients and controls, though there is perhaps rather more uniformity in the last named.

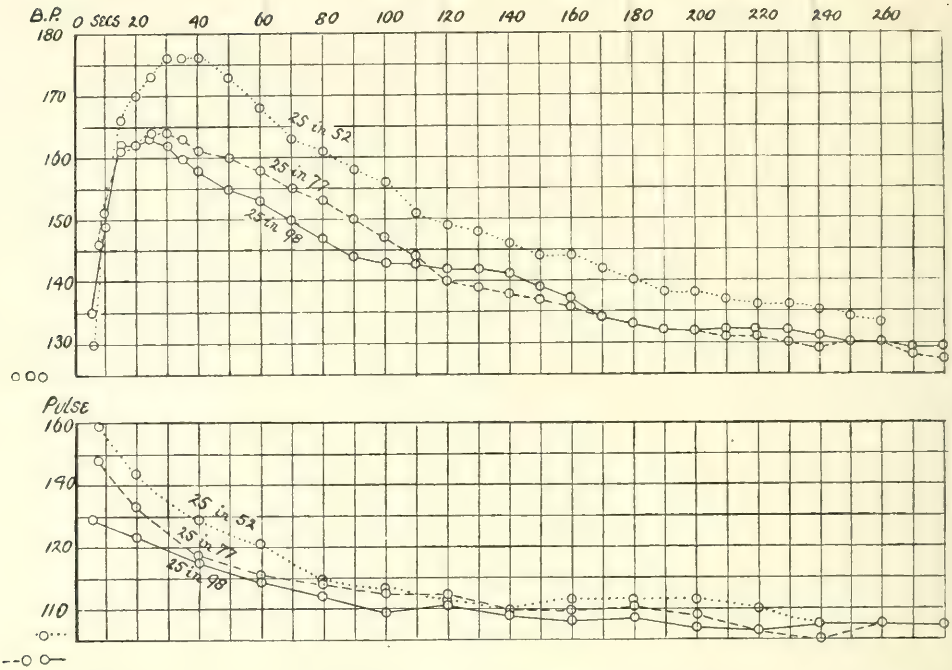


Fig. 7. Similar curves from the same patient as those of Fig. 6, but from a series of exercises in which the amount of work remained constant, the rate of work being increased.

Exceptional Curves.

In two of our patients (*CASES* 5 and 6, Table II) who belonged to a group showing relatively severe symptoms, the initial changes of blood pressure were unusual. The first reading of systolic pressure was unusually high and fell away for 5 or 10 seconds by 2 to 6 mm. Hg.; in the average it rose subsequently again to reach the maximal point. Examples of these curves are shown in Fig. 8.

This preliminary fall was inconstant in these patients, occurring on some days and not on others, occurring on some exercises and not on others. We were unable to ascertain the particular conditions which induced it.

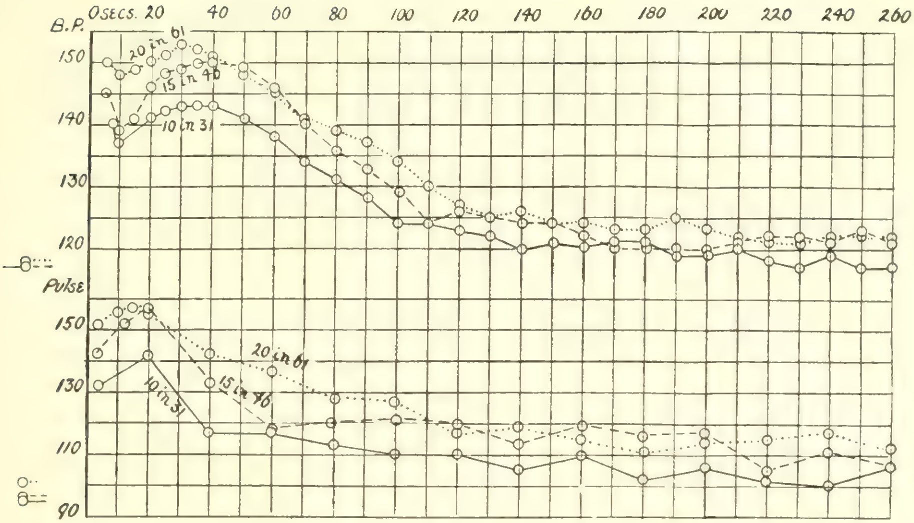


Fig. 8. Averaged curves of B. P. and P. R. from a patient in whom the symptoms of "irritable heart" were relatively severe. The curves are exceptional in showing preliminary falls of blood pressure and preliminary rises of pulse rate.

In one patient (No. 6) it was associated with the preliminary rise of pulse rate presently to be described. According to our view a preliminary and steep fall of pressure occurs in normal people and in all patients, though it is usually so brief that it cannot be identified. We presume that in these two instances the end of the fall was delayed so that we were able to witness its termination. There is, however, a reservation ; and that is the association of the fall of pressure with a preliminary increase of pulse rate in one instance (Fig. 8).

It is customary for the pulse rate to decline uniformly from the termination of exercise in controls and patients; in two of the latter (*CASES* 6 and 7) a preliminary rise of rate, averaging 4-16 beats per minute, was seen, though not with constancy, and lasting some 3-15 seconds. This rise was the more remarkable since it occurred most conspicuously or was confined to exercises in which the full effort was not approached. We are unable to offer any satisfactory explanation for it.

The curves have no considerable importance in irritable heart cases, as they are clearly exceptional and were obtained in patients who presented severe symptoms of the affection.

Variations in the height and duration of blood pressure and pulse rate rises occur from day to day in controls and patients, exceptionally to a remarkable degree. The meaning of such variations we have not attempted to study. When a remarkable change has occurred during the progress of a series of observations we have repeated that series; the minor variations, which are of greater frequency, have induced us to triple our observations upon a given subject.

THE PULSE RATE AFTER A SIMPLE TEST EXERCISE IN CASES OF "IRRITABLE HEART."*

By J. C. MEAKINS and E. B. GUNSON.

(*From the Military Hospital, Hampstead.*)

Our objects have been to investigate the relation of palpitation to pulse rate and the relation of the duration of palpitation to the return of the rate to normal after a definite amount of exercise. Various test exercises were at first employed, but it soon became evident that a very simple form was essential in order that the test exercise might be accomplished by all patients, no matter how severe their symptoms. It was decided eventually to employ a simple marching and stair-climbing test ; a walk of 75 paces at ordinary quick time terminating with the climbing of 27 steps (18 feet) was adopted as the standard.

Before the test exercise was given the pulse rate was taken with a polygraph for about one minute, when the patient had been in the sitting position for some minutes. The wristlet was left in position during the test. On his return from the exercise he resumed the sitting posture, the polygraph was started and the tube connected. A continuous record was taken until the pulse returned to normal. When the test was completed the pulse rate was counted from the polygraph tracing in six-second periods until the estimated rate per minute of any six-second period was the same as before the test exercise. The half-minute, in which this occurred, was taken as the period at which the pulse returned to normal, that is, if the pulse rate were 70 before the test exercise and returned to between 70-75 during a six-second period in the ninth half-minute, it was recorded that the pulse rate had returned to normal in 4½ minutes. A latitude of 5 beats per minute was allowed, as many showed this degree of variation when at rest. It is important to count the pulse rate at each six-second period, as occasionally a quick return to normal or sub-normal is sustained for a few seconds only, and the pulse rate again rises and may not return permanently to the normal for several minutes. Such cases are examples of quick return.

Fifty-two cases of "irritable heart" were investigated after this manner ; a varying number of observations being made on different cases. (See Figs. 1 and 2.)

---

* Work undertaken on behalf of the Medical Research Committee.

Pulse rate before the test exercise. As a general rule the pulse rate in these cases is more rapid than normal. The average rate when at rest in the sitting posture was 86 per minute, while the average rate in a number of healthy male adults was 75 per minute (Fig. 1).

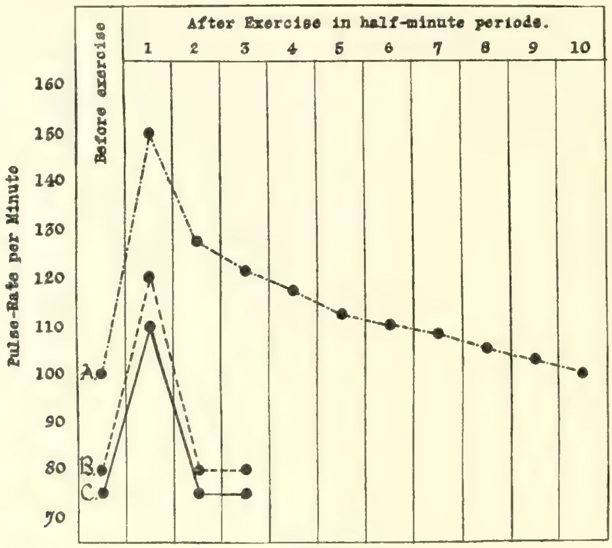


Fig. 1.

A. Compound curve of 10 normal cases.

B. Compound curve of 18 cases with no material symptoms after test exercise.

C. Compound curve of 21 cases with symptoms after test exercise.

Pulse rate immediately after the test exercise. The increase of pulse rate immediately after exercise is relatively more marked than in normal cases, the average maximal rates being 131 to 110. (See Figs. 1 and 2.)

The return of the pulse to normal after the test exercise. In all these cases the relation between the duration of the palpitation and the return of the pulse rate to normal was very striking. The longer the pulse rate took to return to normal the more persistent was the palpitation. In many patients the palpitation ceased suddenly and in these cases the pulse rate returned to normal with a sudden drop of 20 to 30 beats per minute and this drop coincided with the cessation of the palpitation (Fig. 2 *A*). In other cases the palpitation gradually ceased, so that the patient could not tell exactly when it had stopped, and in these cases the pulse rate returned to normal gradually (Fig. 2*B*). It may be stated that the duration of the palpitation was in direct ratio to the length of time the pulse rate took to return to normal.

In Fig. 1 are compound curves of forty-nine cases. Fig. 1 *A* consists of 10 normal adult males; Fig. 1 *B* is the average curve of those cases illustrated in Fig. 2 *A*. The close resemblance to the normal curve is apparent and the absence of material symptoms in these cases after the test exercise was further evidence of their approach to the normal. It was in these cases that the palpitation was of short duration or ceased suddenly with the abrupt fall in the pulse rate. The compound curve of cases illustrated in Fig. 2 *B* is found in Fig. 1 *C*. Here there is a wide departure from the normal. The initial pulse rate is much higher than normal and the increase after exercise more pronounced. Also the return of the pulse rate is slow in contra-distinction to the sudden drop in the normal cases. It was in these patients that the palpitation was prolonged and disappeared slowly.

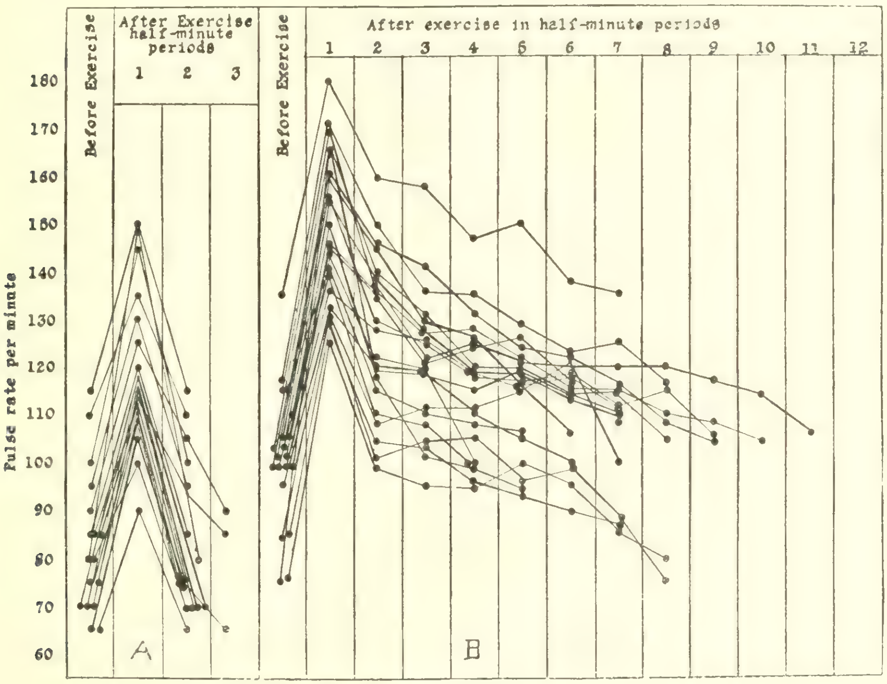


Fig. 2.

Of the fifty-two cases of "irritable heart" tested, in thirty-two the normal pulse rate returned within a minute, and in twenty cases after one minute. On analysing the severity of the symptoms produced by this simple exercise it was found that those in whom the pulse rate returned to normal within one minute had little or no distress, while those in whom the pulse took longer to return had more marked symptoms. In fact, the severity of the symptoms and the length of time it took the pulse to return to normal were in direct ratio.

As all these patients were treated by means of graduated exercises extending over several weeks or months, an opportunity was afforded to compare the return of the pulse rate to normal on a mild exercise with the general and ultimate fitness of soldier for duty. As already stated, these exercises are graduated; the early grades are very light but gradually become more and more severe, as the patient's tolerance warrants, until the final exercise is reached. This final exercise is supplemented by route marches of from 4 to 7 miles, at first without a pack and later with a pack and full equipment. The exercises are numbered as follows (beginning with the least severe): A. 15,* B. 15, C. 15, AB. 30, BC. 30, C. 30, and D. 30. A patient never undertakes a route march without having completed satisfactorily D. 30.

The thirty-two patients in whom the pulse returned to normal within one minute performed these exercises as in Table I.

TABLE I.

Number of cases	Exercise which produced material symptoms.
23	.. .. None
1	.. .. Route marches
1	.. .. D. 30
2	.. .. C. 30
3	.. .. B.C. 30
2	.. .. A.B. 30

Thus 72 per cent. of the cases in which the pulse returned to normal within one minute were eventually able to do all the exercises without symptoms. The remaining 28 per cent. were all able to do the more advanced exercises but with a varying degree of efficiency.

The twenty patients in whom the pulse rate did not return to normal within one minute accomplished the exercises indifferently. In Table II a comparison between the occurrence of symptoms on these exercises and the return of the pulse rate to normal on the test exercise is given.

* The letter indicating the grade of exercise and the number its duration in minutes.

TABLE II.

Number of cases.	Exercise which produced material symptoms.	Pulse return to normal.	
		Within 2 min.	After 2 min.
6	A. 15	1	5
6	B. 15	2	4
2	C. 15	0	2
4	AB. 30	3	1
1	BC. 30	1	0
1	C. 30	1	0

Thus 70 per cent. of these cases could not progress beyond the simplest exercises and the remaining 30 per cent. did so with difficulty.

A comparison of the fifty-two cases of "irritable heart" in regard to occurrence of symptoms on the exercises and the return of the pulse rate to normal after the test exercise is found in Table III.

TABLE III.

Number of cases.	Exercise which produced material symptoms.	Pulse return to normal.		
		1st min.	2nd min.	After 2 min.
23	None	23	0	0
1	Route marches	1	0	0
1	D. 30	1	0	0
3	C. 30	2*	1	0
4	BC. 30	3*	1	0
6	AB. 30	2*	3	1
2	C. 15	0	0	2
6	B. 15	0	2	4
6	A. 15	0	1	5

* A certain number of cases marked * in Table III could not progress upon the exercises because of symptoms other than those of "irritable heart."

We have further examined twenty-one cases with the typical symptoms of "irritable heart" but in whom some degree of cardiac enlargement was suspect. No other signs of organic cardiac disease could be found. These

cases were all placed on graduated exercises and the pulse rate recorded after a test exercise as in the others. In Table IV a comparison between the occurrence of symptoms on these exercises and the return of the pulse rate to normal is given.

TABLE IV.

Number of cases.	Exercise which produced material symptoms.	Pulse return to normal.		
		1st min.	2nd min.	After 2 min.
16	A. 15	0	0	16
1	B. 15	0	0	1
0	C. 15	0	0	0
1	AB. 30	0	0	1
1	BC. 30	0	1	0
1	C. 30	1	0	0
1	D. 30	1	0	0

The response of seventy-three cases with symptoms of "irritable heart," with or without enlargement, is found in Table V.

TABLE V.

Number of cases.	Exercise which produced material symptoms.	Pulse return to normal.		
		1st min.	2nd min.	After 2 min.
23	None	23	0	0
1	Route marches	1	0	0
2	D. 30	2	0	0
4	C. 30	3	1	0
5	BC. 30	3	2	0
7	AB. 30	2	3	2
2	C. 15	0	0	2
7	B. 15	0	2	5
22	A. 15	0	1	21

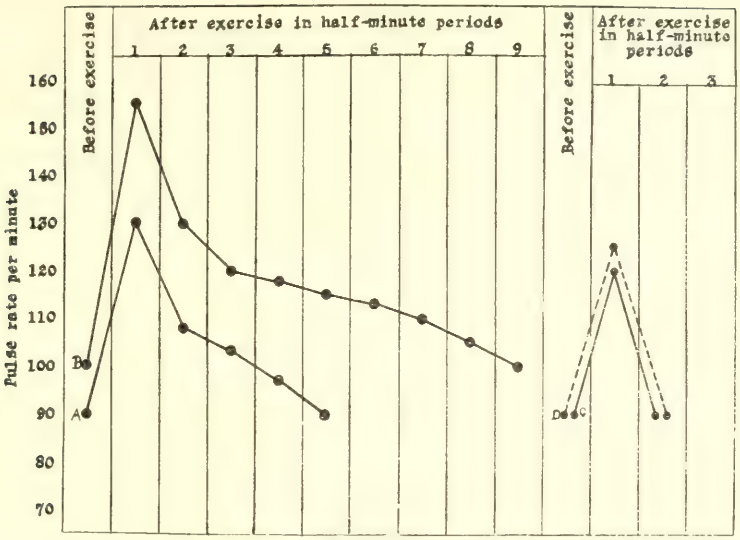


FIG. 3.

Pulse rate in relation to rest in bed.

A. Compound curve of 12 cases before rest in bed.
B. Compound curve of 12 cases after rest in bed.
C. Compound curve of 7 cases before rest in bed.
D. Compound curve of 7 cases after rest in bed.

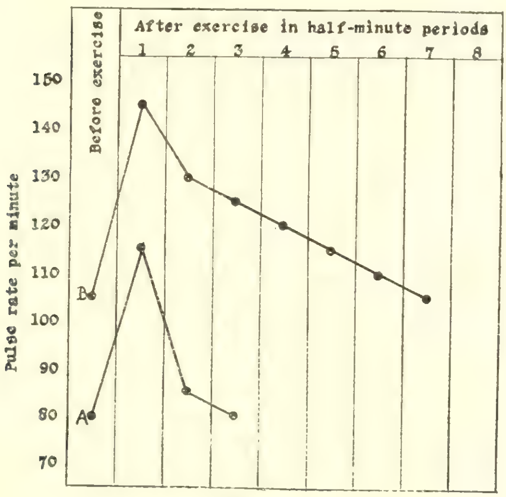


FIG. 4.

Pulse rate in relation to infections.

A. Compound curve of 4 cases before an acute infection.
B. Compound curve of same 4 cases after an acute infection.

The effect of rest in bed upon the pulse rate in response to exercise.

It was frequently found that after one week's rest in bed the pulse rate in response to the test rose to a higher level and remained raised for a longer period than when the patient had been up all day for some time. This was tested in nineteen cases. In seven cases there was little or no change before and after rest in bed. These patients had very slight symptoms after the exercise and the rest in bed seemed to have no effect on their condition (Fig. 3*C* and *D*). In twelve cases, however, a conspicuous change in the return of the pulse rate to normal was observed. The initial pulse rate was higher, it rose to a higher level after the exercise and took longer to return to normal than after these patients had been up all day for a week (see Fig. 3*A* and *B*). Furthermore the symptoms produced in these cases by the test exercise were more severe after rest than after they had been up for a week.

The effects of intercurrent infections upon the pulse rate in response to exercise.

In four cases of irritable heart an intercurrent infection (two tonsilitis, one bronchitis and one influenza) permitted us to observe the effect of this on the return of the pulse rate to normal after the test exercise. An observation on each case had been made shortly before the infection. A compound curve of these observations is shown in Fig. 4. In each case a week was allowed to elapse between the time the patient was first out of bed all day and the second observation. A compound curve of these results is shown in Fig. 4. A comparison of these two curves shows the initial pulse rate to be much higher after the infection than before ; the response of the pulse rate to exercise is much higher and a much longer period elapses before the pulse rate returns to normal. The symptoms produced by the test exercise were more severe after than before the infection.

Conclusions.

1. The presence and duration of palpitation after exercise bear close relations to the degree of cardiac acceleration and to the return of the pulse to normal.

2. The patients in whom the pulse rate did not return to normal within a short period of time performed the simplest exercises with difficulty.

3. Rest in bed has a deleterious effect on the response of the pulse rate to exercise in cases of "irritable heart."

4. Acute infections occurring in individuals with "irritable heart" accentuate the symptoms, produce a conspicuous increase in the pulse rate before and after exercise and cause a pronounced delay in the return of the pulse rate to normal.

OBSERVATION UPON ATROPINE.*

By T. F. COTTON, D. L. RAPPORT and THOMAS LEWIS.

(*From the Military Hospital, Hampstead.*)

A STRIKING feature of soldiers who suffer from "irritable heart" is accelerated cardiac action in response to stimuli which in the normal subject are inadequate to produce a reaction similar in degree. The pulse rate in patients at rest is not materially greater than in normal subjects of the same sex and age; thus it is normal or nearly so during sleep; it is but little raised after a prolonged rest in the supine position. But exercise or emotion or the upright posture raises the rate abnormally.

The rate of the heart is often so susceptible that the greatest care has to be exercised in protecting the subject against accelerating influences, if rates approaching the normal are to be observed. In all averages, therefore, the rates calculated for patients somewhat exceed those of controls; and the divergence is the greater the less adequate the safeguards.

In testing the effects of atropine we have examined 7 patients and 6 controls; and the dose administered intravenously has been equivalent to ·002 grain of the sulphate per stone of body weight (*i.e.*, 1/50 grain in a 10-stone man).

A constant routine has been maintained: the subject lies supine and at rest for ten minutes; for five minutes instrumental records of pulse rate and respiration are taken, the blood pressure and size of pupil are also recorded. The subject then submits to a test exercise, consisting of a brisk walk along a corridor, down a flight of 60 stairs, along a corridor and up the stairs. The time taken for this exercise has been sufficiently constant in patient and control. Immediately upon returning from it, the subject lies down again. The pulse rate, etc., are recorded during the first half-minute of rest and these observations are continued for 10 minutes when the dose of atropine is given. The records continue for 20 minutes and then, while the atropine reaction is still at its height, the test exercise is repeated and its effects compared with those of the first test.

---

* Work undertaken on behalf of the Medical Research Committee.

Heart rate. Our detailed results, in so far as they concern heart rate, are to be found in Tables I and II ; our averaged results are to be seen in the accompanying chart (Fig. 1). The average resting rate of the pulse in the controls was 79 ; in the patients 84. The test exercise raised the pulse more in the patients than in the controls (to 132 at the end of the half-minute in the former, and to 111 in the latter). The fall of rate was rapid in both series, but it was less complete in the patients, standing still somewhat above the resting rate (*i.e.*, at 92) when atropine was injected. In controls and patients the heart rate was rapidly raised by atropine. The rise, as shown in the chart, is approximately the same in the two series. The patients' curve soon falls a little and then runs level and parallel to that of the controls. This slight fall in the patients is attributable to the falling pulse rate at the time of the injection (dotted line). Judging from the actual rise and from the effect of the atropine as it is continued, it is apparent that the effect of the drug upon the patients' heart rate and control heart rate is identical ; the pulse rate is raised 26 beats per minute (79 to 105 in the controls and 84 to 110 in the patients). The second test exercise raises the pulse rate in patient and control conspicuously ; and as in the first test the rise in the patient is the greater (to 161 in patient and to 140 in the control), the difference of 21 beats between them being the same before and after atropine. The actual rise is greater in both patient and control in the second test exercise than in the first. The difference is small, but is more notable because the second test exercises were accomplished somewhat less rapidly than were the first.* It may be explained if we assume the rise of heart rate during exercise to be in the main a sympathetic effect and the subsequent fall to be conditioned by an abrupt increase of vagal tone. It is to be emphasised that we do not state the rise of heart rate *during* exercise to be greater after atropine ;† our observation is that the first rates recorded during the period of rest after exercise and *while the rate is falling* stand at a higher level above the pre-exercise rate in the atropinised subject. Our conclusion is that the fall of pulse rate after exercise is largely conditioned by inhibitory influences which in atropinised subjects are withheld. The subsequent readings are confirmatory of this view ; one minute after the termination of exercise, the reading stands higher by comparison with pre-exercise readings in both patients and controls after atropine. Briefly, in the initial phases of slowing, the pre-exercise rates are less completely restored ; ultimately pre-exercise rates are reached, and the actual time taken for this complete restoration is not materially altered by atropine either in patients or controls.

A relatively high heart rate during the first few moments of rest following exercise is in our view ascribable to a deficient regulating mechanism ; the inhibitory system fails to exert its full grip with natural promptitude. The

* Because distress under exercise often supervened.

† Upon this point we have no facts to record.

maintenance of high pulse rates after the cessation of exercise in irritable heart cases is a conspicuous symptom, and it is to a lag of the vagal grip, rather than to insufficient power of the inhibitory influences, that we ascribe it. That the tone of vagal cardiac nerves is not decreased in those who suffer from irritable heart is shown by the equal reaction of the heart at the injection of atropine. Lack of vagal tone does not appear to us to be responsible in irritable hearts for the general high pulse rates observed in those cases, or the exaggerated response of the heart rate to exercise and exertion. To explain these phenomena, we must suppose a hyper-irritability of some portion of the system which includes the accelerator reflex arc and the rhythm-producing centre itself.

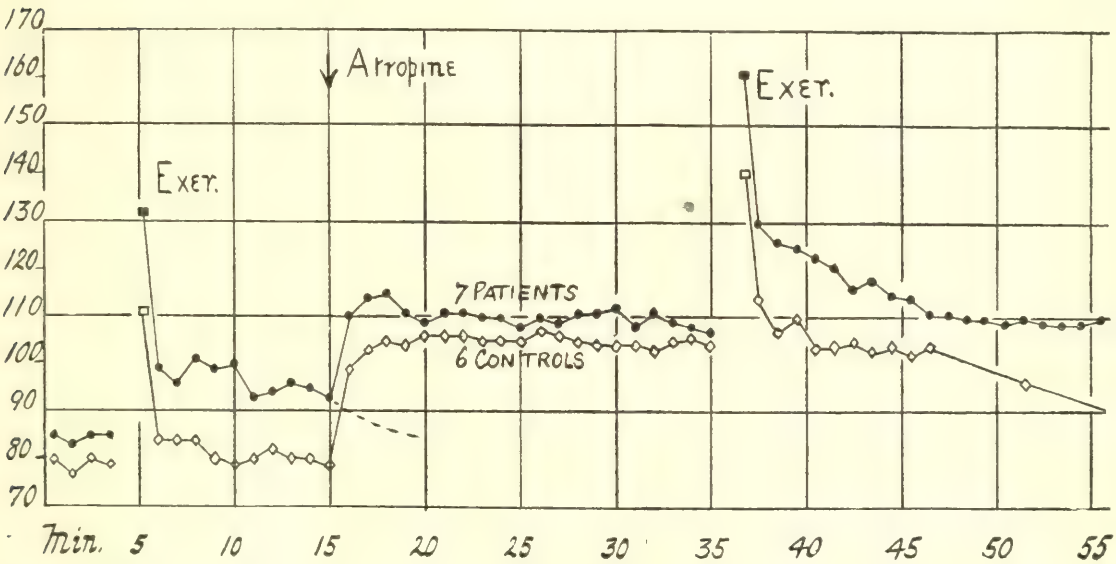


FIG. 1.

Blood pressure. The average systolic blood pressure in the controls was 109 mm. immediately before atropinisation ; it rose to 113 mm. by the end of the first minute following the injection and was continued at almost this level (114-115) for the full period of observation. In the patients the initial systolic pressure averaged 117 mm. ; it rose to 121 by the end of the first minute after the injection and fell to the original level again in about eight minutes. These changes were insignificant.

Respiratory rate. In the controls the initial respiratory rate averaged 19·5 per minute ; it was at 26 after the first exercise and quickly fell again to 20. The injection of atropine reduced it to 18 per minute ; after the second exercise it was raised to 23 per minute.

TABLE I.

EFFECTS OF EXERCISE AND ATROPINE ON PULSE RATE IN SIX CONTROLS.

CONTROL. Weight.	V. 8st. 10lb.	L. 10st. 7lb.	C. 11st. 11lb.	K. 10st. 7lb.	R. 9st.	W. 8st. 12lb.	—
Lying at rest 4 minutes	82	86	68	88	72	83	At rest
	84	81	64	88	70	83	
	90	86	64	87	72	83	
	82	84	64	86	72	83	
Exercise 1½ min.							
During 1st ½ min.	126	120	76	130	118	96	
End of 1st min.	76	92	64	100	86	84	
,, 2nd ,,	84	87	62	93	76	100	
,, 3rd ,,	88	86	62	94	72	100	
,, 4th ,,	92	84	60	86	72	93	
,, 5th ,,	84	84	65	88	68	86	Effect of Exercise
,, 6th ,,	84	80	62	87	72	82	
,, 7th ,,	85	88	65	88	71	93	
,, 8th ,,	82	81	68	89	76	89	
,, 9th ,,	81	84	68	90	74	92	
,, 10th ,,	86	85	68	84	72	81	
Atropine intravenously (·002 grain per stone.)							
End of 1st min.	108	102	81	109	84	108	
,, 2nd ,,	110	106	88	118	88	110	
,, 3rd ,,	104	109	88	119	92	117	
,, 4th ,,	102	104	86	117	96	118	
,, 5th ,,	104	110	91	116	102	115	
,, 6th ,,	100	108	88	118	104	116	
,, 7th ,,	108	109	92	115	100	116	
,, 8th ,,	104	102	89	118	100	118	
,, 9th ,,	106	100	89	115	100	118	
,, 10th ,,	108	100	88	118	103	112	Effect of Atropine
,, 11th ,,	115	100	86	116	110	116	
,, 12th ,,	108	98	87	114	100	122	
,, 13th ,,	106	102	88	115	100	120	
,, 14th ,,	108	98	89	113	100	118	
,, 15th ,,	114	96	89	113	98	116	
,, 16th ,,	108	94	86	115	102	120	
,, 17th ,,	98	94	88	114	97	118	
,, 18th ,,	110	92	87	113	100	116	
,, 19th ,,	112	96	85	108	103	117	
,, 20th ,,	100	98	86	111	103	114	
Exercise 1½ min.							
During 1st ½ min.	150	126	100	158	150	154	
End of 1st min.	110	104	84	131	124	130	
,, 2nd ,,	114	102	90	120	90	124	
,, 3rd ,,	114	96	92	122	112	124	
,, 4th ,,	110	94	82	116	105	110	
,, 5th ,,	112	98	80	112	106	116	Effect of Exercise
,, 6th ,,	114	97	81	114	103	120	
,, 7th ,,	110	98	79	111	103	114	
,, 8th ,,	112	97	80	110	100	122	
,, 9th ,,	110	93	79	112	100	120	
,, 10th ,,	108	100	78	111	—	120	
,, 15th ,,	100	—	74	100	105	100	
,, 20th ,,	92	—	76	—	99	98	

TABLE II.

Effects of exercise and atropine on pulse rate in seven patients.

Patient. Weight.	D. 11st. 10lb.	R. 10st. 10lb.	Z. 9st. 11lb.	S. 10st. 2lb.	C. 9st. 6lb.	G. 10st. 2lb.	P. 10st. 3lb.	—
Lying at rest	80	80	110	82	80	78	84	
4 minutes	84	80	110	78	74	78	84	At rest
	88	80	110	84	74	78	84	
	90	80	110	75	78	78	84	
Exercise 1½ min.								
During 1st ½ min.	142	148	154	104	132	108	134	
End of 1st min.	112	82	138	76	74	82	132	
,, 2nd ,,	108	78	132	74	82	74	122	
,, 3rd ,,	108	96	120	94	84	82	122	
,, 4th ,,	104	94	122	94	83	94	114	
,, 5th ,,	100	96	112	100	82	94	114	Effect
,, 6th ,,	94	84	102	92	81	84	112	of
,, 7th ,,	94	—	104	96	75	90	110	Exercise
,, 8th ,,	96	88	112	88	77	104	106	
,, 9th ,,	102	84	102	92	77	92	108	
,, 10th ,,	94	86	108	88	82	88	108	
Atropine intravenously (·002 grain per stone).								
End of 1st min.	114	112	104	86	80	130	146	
,, 2nd ,,	118	116	94	114	78	133	145	
,, 3rd ,,	115	108	104	118	75	132	150	
,, 4th ,,	116	110	104	116	70	123	140	
,, 5th ,,	114	108	98	114	68	123	140	
,, 6th ,,	114	104	106	111	75	124	140	
,, 7th ,,	114	108	112	110	78	116	141	
,, 8th ,,	114	108	112	112	75	115	136	
,, 9th ,,	114	108	114	112	77	115	133	
,, 10th ,,	114	110	118	110	80	118	—	Effect
,, 11th ,,	114	120	114	110	79	118	125	of
,, 12th ,,	114	112	114	104	74	120	123	Atropine
,, 13th ,,	112	110	118	108	75	123	132	
,, 14th ,,	110	110	126	110	77	118	126	
,, 15th ,,	114	115	132	104	74	120	124	
,, 16th ,,	108	110	132	106	78	116	—	
,, 17th ,,	112	106	132	108	80	116	122	
,, 18th ,,	112	106	132	104	78	112	122	
,, 19th ,,	108	106	132	106	77	—	122	
,, 20th ,,	110	106	132	100	73	—	122	
Exercise 1½ min.								
During 1st ½ min.	158	—	182	164	156	140	168	
End of 1st min.	124	112	178	130	96	116	157	
,, 2nd ,,	122	115	154	124	96	120	148	
,, 3rd ,,	112	121	152	122	90	125	154	
,, 4th ,,	112	120	146	120	90	120	152	
,, 5th ,,	115	122	140	112	90	117	150	
,, 6th ,,	115	105	134	112	87	116	143	
,, 7th ,,	115	115	140	110	90	114	140	
,, 8th ,,	114	104	134	113	87	110	140	
,, 9th ,,	114	105	134	105	87	107	143	Effect
,, 10th ,,	118	105	128	110	89	108	142	of
,, 11th ,,	114	105	138	108	90	—	—	Exercise
,, 12th ,,	115	105	136	108	90	—	—	
,, 13th ,,	115	105	134	108	90	—	—	
,, 14th ,,	116	105	130	108	90	—	—	
,, 15th ,,	112	105	120	108	90	102	127	
,, 16th ,,	110	105	134	108	92	—	—	
,, 17th ,,	110	105	132	108	92	—	—	
,, 18th ,,	108	105	134	108	92	—	—	
,, 19th ,,	109	105	134	108	92	—	—	
,, 20th ,,	109	105	134	108	92	102	120	

In the patients the initial rate averaged 26 per minute ; after the first exercise it was raised to 35 per minute, from which level it had fallen to 30 when atropine was administered. It subsequently descended to 28, to be again raised to 42 (average of highest level reached) in the period following the second exercise.

Other symptoms during the twenty minutes following the atropine. Dryness of the mouth developed in all the controls soon after the injection ; in one case palpitation was experienced.

In the patients dryness of the mouth was always experienced ; in several there was palpitation. In one instance only was dilatation of the pupils seen during the hour of observation ; but it was the rule to find it some hours later.

Summary.

1. The effects of atropine in patient and control are identical, except in so far as the reactions are affected by the previous condition of the subject.

2. The sensitivity of the patient's heart in respect of its acceleration to slight stimuli is attributed to hyper-irritability of some portion of the system which includes the accelerator reflex arc.

3. The delay in the fall of the raised pulse rate following exercise is attributed to delay in the action of the vagus nerve.

OBSERVATIONS UPON PILOCARPINE NITRATE.*

By T. F. COTTON, J. G. SLADE and THOMAS LEWIS.

(*From the Military Hospital, Hampstead.*)

The effects of pilocarpine nitrate have been observed in eight patients suffering from "irritable heart" and in six controls. After a period of rest in the supine position, and after preliminary observations, the drug is injected beneath the skin of the upper arm. The dosage employed is varied with the weight of the subject. At the first injection, 1/100 grain per stone of weight is administered; after an interval of several days, a second injection of 1/50 grain per stone of weight is given. We take records of pulse rate per minute and the rate of swallowing per five minutes throughout, and at each five minutes' interval the blood pressure and respiratory rate are read. Notes are made upon sweating, lacrymation and the appearance of goose skin.

In none of our six controls have we observed any constant or considerable change of pulse or respiratory rate, or any notable fluctuations of the blood pressure. The same statement applies to our eight patients, with the exception that there appeared to be an inconspicuous or moderate fall of pulse rate in some instances towards the end of an hour's observation; during the height of the reaction the pulse rate was unchanged or a very little raised. The only conspicuous reactions were sweating, salivation, lacrymation and goose skin, the latter usually accompanied by shivering.

Sweating in controls. The smaller dose, approaching 1/10 grain, produced conspicuous sweating in one subject, moderate sweating in one, slight sweating in two, while in two there was no reaction. Sweating begins eight or ten minutes after the injection, except where the reaction is very slight, when the onset is later; beads of sweat first appear on the scalp, neck or face, and spread in variable degree to the chest and limbs. The reaction lacks uniformity in degree. With the heavier dose, approximately 1/5 grain, sweating was conspicuous in four subjects and moderate in the remaining two. When this dose is employed sweating starts five to fifteen minutes after the injection; the head and neck are first affected, and the whole body becomes involved in most instances; the reaction to this dose is tolerably uniform from subject to subject.

* Undertaken on behalf of the Medical Research Committee.

Sweating in patients. The reaction of the eight patients to the smaller dose was more conspicuous than in the controls ; the reaction to the larger dose was similar in patients and controls.

	Sweating (1/10 grain)				Sweating (1/5 grain)		
	Consp.	Mod.	Sl.	None.	Consp.	Mod.	Sl.
6 controls	1	1	2	2	4	2	0
8 patients	0	6	2	0	5	2	1

The reaction is fairly uniform in the patients, being moderate to the small dose in all but two subjects, and conspicuous or moderate to the heavy dose in all but one. The time and place of onset and the extent of sweating is similar in patients and controls. Sweating in controls and patients decreases and almost vanishes by the end of an hour, though in many the skin is unusually moist for hours subsequently.

Salivation. The rate of swallowing in six controls before injection averaged 3 per five minutes. The smaller dose raised the rate to an average maximum of 11 per five minutes, the larger dose to a rate of 16. In our patients the average rate of swallowing before injection was higher, namely 5 per five minutes ; the rate after the small dose of pilocarpine was raised to an average maximum of 15, and after the large dose to 23. In both controls and patients the rate of swallowing is frequently increased at the end of five minutes or ten minutes ; it is at its height during the period from fifteen to thirty minutes after injection and gradually decreases from that time onwards. The majority of those to whom the drug has been administered complain of increased salivation for many hours after the observation.

Lacrymation. Excessive secretion of the lacrymal glands, giving rise to glistening of the eyeball, accelerated blinking, or a collection of tears almost to the point of overflow, is a constant reaction. It has been more conspicuous in our patients than in our controls, both upon the smaller and heavier dose.

	Lacrymation (1/10 grain)			Lacrymation (1/5 grain).		
	Consp.	Mod.	Sl.	Consp.	Mod.	Sl.
6 controls	0	1	5	1	3	2
8 patients	1	5	2	6	2	0

With the heavier dose the onset is usually within the first five minutes ; it is often the first sign of a reaction. It is fully displayed twenty to forty minutes after the injection and in most subjects has subsided almost completely at the end of an hour.

Other symptoms. Goose skin appears in patients and controls at the height of the reaction (10-25 minutes after injection) and is usually accompanied by shivering It subsides within the hour.

In a number of controls and patients increase in urine flow makes itself evident.

TABLE I.

ACTION OF PILOCARPINE NITRATE IN CONTROLS.

W.* Age 31. Weight 8st. 8lb. Dose ·08 grain. 27/6/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55
Pulse rate ..	102	100	94	102	92	92	92	87	84	89	88	90
S. B. P. ..	112	112	110	108	112	110	110	112	108	110	108	112
Resp. rate ..	22	24	22	20	22	20	20	20	20	20	20	20
Swallowing† ..	4	3	3	5	? 3	6	6	—	3	5	2	4
Sweating ..					onset ?		full ?					
Lacrymation						onset						gone

Sweating and lacrymation very slight.
Goose skin, 25 minutes.

Dose ·16 grain. 30/6/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55
Pulse rate ..	87	98	102	96	103	95	91	85	77	80	78	70
S. B. P. ..	104	106	104	108	112	110	110	110	110	110	104	106
Resp. rate ..	20	22	20	20	22	24	22	20	24	20	20	22
Swallowing ..	3	8	9	10	8	11	7	9	5	6	5	6
Sweating		onset face neck		full face head hands body			de	creasin	g			
Lacrymation		onset		full			de	creasin	g			

Sweating and lacrymation considerable.
Goose skin at 5 minutes.

* Always sweats easily on exercise. Hands often moist at rest.

† Rate per five minutes.

TABLE I—*continued.*

R.* Age 25. Weight 8st. 12lb. Dose ·1 grain. 5/7/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55
Pulse rate ..	72	72	71	67	66	68	63	70	68	65	58	
S. B. P. ..	116	115	115	120	120	119	117	118	118	120	120	
Resp. rate ..	18		19	15	15	18	18	18	18	20	16	
Swallowing ..	4	8	10	11	17	12	14	13	9	8	7	
Sweating ..		8 min. onset cheek neck		fore-head chest		full conspi	cuous	decr	easing	gone		
Lacrymation				12 onset		full sl.		decr	easing	gone		

Goose skin on chest at 10 minutes, at 20 minutes and 30 minutes and 50 minutes.
Shivering at 10 minutes.
Sweating conspicuous; lacrymation slight.

Dose ·2 grain. 8/7/16.

Pulse rate ..	60	75	70	60	68	65	64	65	58	58	60	60
S. B. P. ..	110	112	114	116	114	116	120	120	124	122	122	120
Resp. rate ..	20	24	18	18	24	24	20	20	20	24	22	20
Swallowing ..	4	8	22	25	18	16	11	13	10	9	12	10
Sweating ..			face neck onset	full genera	l			de	creasin	g		still present slight
Lacrymation			onset	full				de	creasin	g		still present slight

Goose skin, 10 minutes (chest and arm). Cold, 20 minutes; goose skin conspicuous.
Sweating very profuse; lacrymation moderate.
Cold and shivering at 25 minutes and 45 and 55.
Desire to urinate at 25 minutes.

S.† Age 40. Weight 12st. 10lb. Dose ·13 grain. 3/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	60
Pulse rate ..	64	66	67	69	70	67	69	69	69			
S. B. P. ..	114	112	—	110	112	—	116	—	112			
Resp. rate ..	20	20	—	20	20	—	13	—	16			
Swallowing ..	2	5	6	14	12	13	12	10	8			
Sweating ..	no	ne										
Lacrymation				onset	full			de	creasin	g		

Lacrymation moderate in amount.

* Always sweats fairly easily on exercise.

† Sweats fairly easily on exercise.

TABLE I—*continued.*

Dose ·26 grain. 20/5/16.

Pulse rate ..	68	69	72	85	79	70	75	80	71	70	76	76
S. B. P. ..	104	104	106	108	110	112	114	116	116	108	116	118
Resp. rate ..	18	18	16	18	18	16	16	17	16	18	17	16
Swallowing ..	6	5	9	12	12	13	15	14	12	14	13	13
Sweating ..				onset (face)	face body hands	full				de	creasin	g
Lacrymation				onset			full		de	creasin	g	gone

Sweating considerable; lacrymation moderate.
Goose skin present.

L.* Age 34. Weight 10st. 7lb. Dose ·11 grain. 4/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	77	77	81	82	83	81	78	75	78				
S. B. P. ..	121	120	—	120	—	120	—	122	—				
Resp. rate ..	16	16	—	16	—	16	—	18	—				
Swallowing ..	3	2	4	10	13	11	10	10	8				
Sweating ..			slight flush	onset (head)	head face chest neck	legs also	full whole body		decre	asing			
Lacrymation			onset		full		d	e c r e	a s i n	g			

Sweating moderate; lacrymation slight. Goose skin, 10 minutes.

Dose ·2 grain. 22/5/16.

Pulse rate ..	88	85	85	90	90	84	90	88	85	84	84	82	85
S. B. P. ..	108	108	108	106	106	106	108	112	—	112	108	106	—
Resp. rate ..	20	18	18	20	16	18	20	16	—	20	20	18	—
Swallowing ..	1	4	3	6	9	11	11	12	9	7	10	8	6
Sweating ..			slight flush	onset (head)	head axillæ abdomen	face and legs also	full whole body	same	same	same		decreasing	
Lacrymation			onset		full				de	creasin	g		

Sweating considerable; lacrymation slight.
Urine flow increased, large quantity urine of low sp. gr. passed.
Goose skin, 10 minutes.

* Sweats fairly easily on exercise.

TABLE I—*continued.*

C.* Age 31. Weight 11st. 7lb. Dose ·115 grain. 3/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	60
Pulse rate ..	72	77	76	77	82	75	73	72	74	70		
S. B. P. ..	116	118	118	120	120	122	118	120	120	—		
Resp. rate ..	19	20	20	18	18	18	19	18	20	—		
Swallowing ..	2	2	3	3	8	6	6	3	0	1		
Sweating ..						nose moist		none				
Lacrymation					onset		full		decr	easing		

Sweating and lacrymation very slight.

Dose ·2 grain. 16/5/16.

Pulse rate ..	84	86	86	88	94	90	83	90	92	93	92	86
S. B. P. ..	122	120	120	120	122	120	120	120	118	118	120	118
Resp. rate ..	24	24	24	18	18	18	18	16	16	16	18	—
Swallowing ..	2	1	4	9	16	16	16	13	11	13	10	5
Sweating ..			onset (head)	face	body legs	full	whole	body		de	creasin	g
Lacrymation			onset				full			de	creasin	g

Sweating moderate. Lacrymation slight.
Urine flow increased.
Goose skin, 13 minutes.

K.† Age 27. Weight 8st. 12lb. Dose ·1 grain. 6/7/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	72	74	80	83	72	80	87	73	70	73	72		
S. B. P. ..	118	112	114	114	116	118	114	116	116		116		
Resp. rate ..	15	15	18	18	17	16	16	17	17		16		
Swallowing..	2	3	4	6	5	4	9	7	7		5		
Sweating ..				n	o t p r	e s e n	t						
Lacrymation				onset	full slight	de	creasin	g gone					

Goose skin appeared before and remained throughout on chest.
Shivering. No sweating, lacrymation slight.

* Sweats moderately on exercise. Hands sometimes clammy at rest.
† Does not sweat easily on exercise.

TABLE I—*continued.*

Dose ·2 grain. 12/7/16.

Pulse rate ..	78	84	80	85	80	82	80	80	80	76	78	
S. B. P. ..	115	118	113	118	118	118	118	116	112	114	118	
Resp. rate ..	15	16	17	17	17	17	12	14	16	14	15	
Swallowing ..	3	3	11	11	15	9	6	7	5	7	5	
Sweating ..		onset (7 min.) brow cheeks			full body face neck		decre	asing			gone	
Lacrymation		onset (7 min.)			full		decre	asing			gone	

Goose skin, arm and chest, at 6 minutes, lasting 10 minutes.
Sweating and lacrymation moderate.
Desire to urinate.

TABLE II.

ACTION OF PILOCARPINE NITRATE IN PATIENTS.

S.* Age 40. Weight 10st. 7lb. Dose ·105 grain. 29/4/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	77	86	84	79	77	83	78	72	79	77	72	70	72
S. B. P. ..	125	128	124	122	120	—	—	—	—	—	122	120	—
Resp. rate ..	28	28	—	—	—	28	—	—	—	—	—	—	27
Swallowing ..	—	—	—	—	—	—	19	24	33	25	27	19	27
Sweating ..						onset (face)	full					decre	asing
Lacrymation						onset	full					decre	asing

Sweating moderate; lacrymation considerable.
Goose skin, 14 minutes.

Dose ·21 grain. 14/5/16.

Pulse rate ..	92	87	86	94	92	86	84	90	88	84	80	72	74
S. B. P. ..	120	120	120	118	118	118	118	118	120	118	118	118	118
Resp. rate ..	24	26	26	26	20	26	24	24	24	24	24	22	24
Swallowing ..	20	19	22	13	17	16	19	19	18	20	18	20	20
Sweating ..					onset (face)	head			full				
Lacrymation		onset							full				

Sweating slight; lacrymation considerable.
Goose skin.

* Always sweats easily and profusely on exercise. Feet and hands clammy at rest.

TABLE II—*continued*.

B.* Age 24. Weight 9st. Dose ·09 grain. 1/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	6
Pulse rate ..	76	78	81	80	82	80	75	76	76	79	84	78	77
S. B. P. ..	126	128	118	120	126	124	—	120	—	—	—	—	—
Resp. rate ..	36	—	—	—	40	—	—	—	—	40	—	—	36
Swallowing ..	5	8	7	7	7	8	8	6	8	12	10	10	6
Sweating ..		onset 5 min.							full		decreasing		
Lacrymation		onset 5 min.							full				

Sweating and lacrymation moderate.

Dose ·18 grain. 14/5/16.

Pulse rate ..	80	80	81	84	78	78	82	77	74	75	73	72	74
S. B. P. ..	110	108	104	108	108	110	112	112	112	115	112	115	115
Resp. rate ..	32	36	34	36	32	32	32	32	32	30	30	32	25
Swallowing ..	7	10	9	20	16	18	18	27	18	16	16	14	9
Sweating ..			onset (face)		head trunk		full whole body				d	ecrea	sing
Lacrymation			onset				full						gone

Sweating and lacrymation conspicuous.
Goose skin, 25 minutes.

C.† Age 20. Weight 10st. 7lb. Dose ·105 grain. 30/4/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	79	83	87	89	81	80	79	77	78	77	78	76	76
S. B. P. ..	116	116	120	—	126	125	—	124	—	128	125	—	—
Resp. rate ..	20	—	—	—	20	—	40	—	30	—	—	—	—
Swallowing ..	5	4	6	13	7	9	5	7	7	11	5	4	3
Sweating ..			onset				full						
Lacrymation		onset 7 min.					full						

Sweating and lacrymation moderate.

* Always sweats easily on exercise. Hands clammy, axillæ sweating, while at rest.

† Always sweats easily on exercise. Hands and feet often sweating while at rest.

TABLE II—*continued.*

Dose ·2 grain. 15/5/16.

Pulse rate ..	98	94	100	100	96	106	105	110	102	103	94	100	98
S. B. P. ..	120	110	116	116	116	116	116	118	120	118	116	120	120
Resp. rate ..	24	20	18	22	18	18	20	20	18	18	18	18	18
Swallowing ..	7	9	8	16	20	21	18	13	16	12	11	12	10
Sweating ..				onset (face)		trunk		full whole body		dec	reasi	ng	
Lacrymation				onset				full		dec	reasi	ng	gone

Sweating and lacrymation moderate.

R.* Age 21. Weight 10st. Dose ·1 grain. 2/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	70	74	85	81	84	75	74	68	68	68			
S. B. P. ..	135	130	130	130	136	—	136	132	—	134			
Resp. rate ..	36	36	36	36	36	—	36	36	—	34			
Swallowing ..	1·5	2	0	2	4	6	4	3	2	3			
Sweating ..					onset	full	de	creasin	g				
Lacrymation				onset			full	decre	asing	gone			

Sweating and lacrymation moderate.

Dose ·2 grain. 16/5/16.

Pulse rate ..	110	100	110	102	98	104	98	102	100	96	98	88	86
S. B. P. ..	140	140	142	143	150	150	150	148	150	148	146	145	144
Resp. rate ..	30	36	36	38	42	40	36	40	38	34	38	42	46
Swallowing ..	7	5	9	14	17	16	9	9	6	6	7	4	4
Sweating ..				onset (fore-head)	neck lips trunk	full whole body				decrea	sing		
Lacrymation			onset			full				decrea	sing		

Sweating and lacrymation conspicuous.
Goose skin conspicuous.

* Sweats profusely and easily on exercise. Hands and feet clammy or wet.

TABLE II—*continued.*

B.* Age 26. Weight 8st. 12lb. Dose ·09 grain. 5/4/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	—	100	80	81	80	79	74	80	80	—	—	—	—
S. B. P. ..	122	—	122	126	124	128	120	124	120	—	—	—	—
Resp. rate ..	22	—	20	22	20	16	24	24	—	—	—	—	—
Swallowing ..	—	4	10	17	10	11	11	12	9	3	7	—	
Sweating ..				onset (face)			full head trunk	de	creasin	g			
Lacrymation			onset				full	de	creasin	g			

Sweating moderate; lacrymation slight.
Goose skin, 20 minutes.

Dose ·18 grain.

Pulse rate ..	86	85	92	90	88	98	93	100	80	74	69	75	82
S. B. P. ..	120	122	122	122	122	132	132	130	130	126	122	122	122
Resp. rate ..	26	32	26	26	20	24	18	20	26	26	28	20	26
Swallowing ..	10	25	20	15	10	15	10	10	5	15	10	10	5
Sweating ..			onset (face)	chest		full whole body			de	creasin	g		
Lacrymation			onset			full			de	creasin	g		

Sweating and lacrymation full.
Shivering with reaction at its height.

L.† Age 22. Weight 10st. 13lb. Dose ·11 grain. 4/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	85	84	84	88	85	80	80	81	78	76	74	76	76
S. B. P. ..	111	112	112	116	114	—	118	112	—	114	116	114	—
Resp. rate ..	28	28	26	26	—	—	20	—	20	20	20	22	—
Swallowing ..	2	1	0	7	11	? 6	11	6	5	6	4	4	4
Sweating ..				onset (face)			full face head hands axillæ				dec	reasi	ng
Lacrymation				onset			full				dec	reasi	ng

Lacrymation and sweating moderate.

* Sweats easily and profusely on exercise. Hands clammy or wet, axillæ sweating at rest.
† Sweats easily and profusely on exercise. Hands wet, axillæ sweating at rest.

TABLE II—*continued.*

Dose ·22 grain. 16/5/16.

Pulse rate ..	70	84	85	80	81	85	88	88	80	80	70	70	70
S. B. P. ..	116	114	112	115	116	122	122	123	116	116	116	116	116
Resp. rate ..	22	22	20	20	16	18	18	18	22	16	18	18	18
Swallowing ..	2	2	13	18	21	14	21	16	14	13	8	5	6
Sweating ..			onset (face)		trunk limbs	full whole body			de	creasin	g		
Lacrymation			onset		full				de	creasin	g		gone

Sweating and lacrymation conspicuous.
Goose skin, 10 minutes.

C.* Age 21. Weight 9st. 6lb. Dose ·09 grain.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	67	71	77	82	78	73	77	76	73	69	70	—	—
S. B. P. ..	114	116	118	124	—	122	—	124	122	122	124	122	—
Resp. rate ..	20	20	—	—	20	—	—	20	28	24	—	24	—
Swallowing ..	2	3	8	11	8	13	10	10	5	4	4	—	—
Sweating ..					onset			full		dec	reasi	ng	
Lacrymation			onset					full		dec	reasi	ng	gone

Sweating and lacrymation slight.

Dose ·18 grain. 10/5/16.

Pulse rate ..	64	74	70	80	70	69	71	70	67	65	62	58	58
S. B. P. ..	108	106	112	116	118	122	128	130	130	130	128	124	122
Resp. rate ..	20	20	24	20	24	16	16	16	18	18	16	20	20
Swallowing ..	5	11	26	30	32	26	19	15	12	10	7	7	8
Sweating ..			onset (face)	chest head		full whole body			de	creasin	g		
Lacrymation		onset 7 min.				full							

Sweating and lacrymation conspicuous.

* Does not sweat easily on exercise. Hands and feet often moist, axillæ sometimes wet, while at rest.

TABLE II—*continued*.

P.* Age 20. Weight 9st. Dose ·09 grain. 2/5/16.

Minutes after	0	5	10	15	20	25	30	35	40	45	50	55	60
Pulse rate ..	80	73	75	78	77	76	78	78	81	79	79	79	75
S. B. P. ..	140	138	138	140	142	138	134	138	138	136	136	136	132
Resp. rate ..	20	23	22	23	24	24	24	—	—	20	28	25	—
Swallowing ..	3	4	3	8	21	12	12	13	10	8	6	1	5
Sweating ..				onset (face)	full slight								
Lacrymation				onset				full		decrea	sing		

Sweating slight; lacrymation moderate.

Dose ·18 grain. 15/5/16.

Pulse rate ..	82	92	106	105	103	102	100	98	94	98	94	85	85
S. B. P. ..	118	122	124	126	126	136	136	138	138	134	136	136	136
Resp. rate ..	20	22	22	26	26	20	22	22	24	24	26	24	26
Swallowing ..	3	2	8	19	27	30	30	18	22	22	24	20	17
Sweating ..				onset (face)		trunk head	limbs	full			de	crea	sing
Lacrymation			onset					full			de	crea	sing

Sweating moderate, lacrymation moderate.
Goose skin, 25 minutes.

Remarks and Conclusion.

There are individuals who sweat profusely while exercising or upon exposure to heat, others sweat little. Of controls and patients, those in whom the sweat glands are known to be active give a full reaction to pilocarpine. Those in whom sweating is less easily produced by natural means are also less affected by pilocarpine. Inasmuch as the sweating of pilocarpine is due to stimulation of the terminal fibrils of the secretory nerves, insomuch variations in skin activity in normal subjects and in our patients, in response to effort and other natural stimuli, are conditioned peripherally. Excessive sweating is a feature of the patients; moisture of the hands is almost constant and sweating from the axillæ is very frequent, even while the subjects are at rest.

Conclusion. The increased activity of the sweat glands, the increased activity of the salivary glands (as estimated by the rate of swallowing), of patients suffering from "irritable heart," appears to be due to hyper-excitability of the corresponding peripheral mechanisms.

* Does not sweat easily on exercise. Hands clammy at rest.

OBSERVATIONS UPON AMYL NITRITE.*

By T. F. COTTON, J. G. SLADE and THOMAS LEWIS.

(*From the Military Hospital, Hampstead.*)

As patients who present the symptoms of "irritable heart" are prone to flush readily, and as accelerated heart rate in them is easily provoked by many causes, a comparison has been instituted between the reaction of normal subjects and those who suffer from irritable heart to the drug amyl nitrite. The results of these observations are summarised in the accompanying tables.

The nitrite of amyl is so administered as to render the dosage as uniform as possible. The subject lies comfortably upon a couch ; sphygmomanometer armlet, arterial pulse receiver and respiratory receiver are adjusted and preliminary readings are taken until these are uniform. A wide tube is held lightly between the closed lips and at a signal the subject takes a single inspiration through the tube, while ·05 to ·06 cc. of amyl nitrite (approximately 1 minim)† is blown into it. The tube is at once removed and natural nasal breathing is resumed. The reaction in seven control subjects, young healthy adults, has been at its height in about twenty to thirty seconds. The flush is confined to the face (three instances) or spreads beyond it to the neck and upper part of the chest. Starting from a normal level the pulse rate rises from 19 to 40 beats per minute ; the rise is less when the preliminary rate is an accelerated one. It averages 24 beats per minute. The maximal rate and the full flush are simultaneous with a fall of blood pressure. The tabulated figures of blood pressure for the first half-minute represent the lowest pressure observed during this half-minute. The fall varies between 12 to 35 mm. Hg.. In respiratory rate and excursion we find little change; a fall of rate is more frequent than a rise in our observations. At the end of one minute after the inhalation, the pulse and blood pressure give normal readings. A sensation of fullness, tension or throbbing in the head is constant. Palpitation of the heart, headache, and giddiness are inconstant with this dosage, being more frequently absent than present.

---

* Undertaken on behalf of the Medical Research Committee.

† The dose of 1 minim was found to be suitable in preliminary observations. Clearly a smaller dose than that customarily employed therapeutically is sufficient when administered by a closed method.

For comparison with these controls we tabulate eleven instances of toxic debility ; in these breathlessness, palpitation, and giddiness were symptoms on exertion ; in most of them spontaneous flushing was frequent, and in most the pulse rate rose steadily as a reaction to exercise. In cases of " irritable heart " the flush is on the average somewhat more vivid and extensive than in the controls, but not materially so. The pulse rate, starting from a normal or slightly increased level, rises between 17 and 64 beats per minute, the average rise being 34. The blood pressure sinks between 11 and 42 mm. Hg., in an exceptional case, 90 mm.. The respiratory rate may remain unchanged, but frequently it is somewhat reduced ; on the other hand it may be raised.

The symptoms in these patients are similar to those found in the controls, though they are a little more prominent, palpitation of the heart being almost constant.

Briefly, our observations show an inconspicuously increased reaction in the abnormal subjects. In these the suffusion of the skin, the rise of pulse rate and the fall of blood pressure are on the whole greater. The difference in reaction, however, is less than we had anticipated.

It has been said that spontaneous flushing in our patients is a common event, it is also frequent, though less so, in healthy subjects ; such flushing may be ascribed to an over-action of the central nervous system or to increased sensibility of the peripheral mechanism.

Amyl nitrite may be used to test this peripheral mechanism, for it is stated to exert its chief action directly upon the small vessels ; a heightened reaction to amyl nitrite therefore would point to sensitiveness of the vessels. Four controls and eight patients were subjects in whom spontaneous flushing was frequent and easily induced ; amongst these twelve subjects the reaction to amyl nitrite was intense in eight, moderate in three, and slight in only one. Of the remaining four controls and three patients, seven subjects in whom spontaneous flushing was experienced but little if at all, two reacted fully, three moderately and two but slightly. It appears to be the rule therefore that the amyl nitrite flush is more conspicuous amongst those in whom spontaneous flushing is prominent, a fact which suggests that the vividness of the spontaneous flush is conditioned more often by the state of the peripheral vessels than by hyper-irritability of the nervous system.

The rise of pulse rate under amyl nitrite is somewhat more conspicuous in our patients than in our controls. It is especially conspicuous in patients in whom the pulse rate is readily accelerated by exercise, emotion, or similar physiological causes. This is clearly established by our table, for in those in whom the pulse rate rises greatly as a response to slight effort, etc., the

CONTROLS.

THE EFFECT OF AMYL NITRITE ON BLOOD PRESSURE, PULSE RATE AND RESPIRATION.

Initial and age.	Weight. st. lb.		Dose.		Before.	After amyl nitrite. ½ min.	1 min.	1½ min.	Flush. Time.	Distrib.	Intensity.	Symptoms following inhalation.
S. Age 28	10.4	Does not flush readily. Pulse not easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	125 65 25	90 90 25	120 70 20	120 62 28	20 sec.	Face only	Moderate	1. Giddiness. 2. Fullness in head. 3. Palpitation.
C. Age 31	11.7	Flushes easily. Pulse little accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	108 74 21	96 100 18	120 80 19	110 72 22		Face, chest, nipples rosy	Vivid	1. Fullness in head. 2. Palpitation.
S. Age 40	12.12	Flushes easily. Pulse little accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	129 93 16	98 112 12	132 85 12	132 82 12	21 sec.	Face, neck	Moderate	1. Flushing. 2. Palpitation. 3. Giddiness. 4. Throbbing in head and singing in ears.
L. Age 34	10.7	Does not flush easily. Pulse little accelerated by exercise.	·05 cc.	B. P. Pulse Resps	108 94 15	88 114 20	106 94 19	108 90 13	20 sec.	Face	Slight	1. Fullness in head. 2. Throbbing in head. 3. Heat, slight giddiness.
M. Age 35	11.4	Does not flush easily. Pulse little accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	116 74 19	86 109 14	116 73 20	116 65 20	28 sec.	Face	Slight	1. Slight fullness of head. 2. Slight throbbing all over.
G. Age 32	11.0	Does not flush easily. Pulse little accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	112 72 24	86 112 18	108 62 21	108 63 16	20 sec.	Face, neck Upper chest	= Full =Slight	1. Head bursting. 2. Headache. 3. Throbbing of head.
B. Age 21	9.7	Flushes easily. Pulse easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	127 117 15	110 121 11	126 118 11	129 82 11	40 sec.	Face, neck and chest	Slight	1. Slight palpitation. 2. Moderate fullness in head.
F. Age 31	10.7	Flushes easily. Pulse little accelerated by exercise.	·05 cc.	B. P. Pulse	125 89	102 118	124 76	125 68	25 sec.	*Face*, neck, chest down to nipples and below	Vivid	1. Feeling of head bursting, also in limbs slight throbbing.

CASES OF IRRITABLE HEART.

THE EFFECT OF AMYL NITRITE ON BLOOD PRESSURE, PULSE RATE AND RESPIRATION.

Initial and age.	Weight. st. lb.		Dose.		Before.	After amyl nitrite. ½ min.	1 min.	1½ min.	Flush. Time.	Distrib.	Intensity.	Symptoms following inhalation.
B. Age 21	13.0	Flushes very easily and intensely. Pulse very easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	116 103 26	(?)120 135 23	100 101 23	114 85 20	18 sec.	Face and upper part of chest	Vivid	Hot and sweating. Palpitation. Slight fullness in head.
B. Age 21	9.8	Flushes easily. Pulse not readily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	111 75 34	90 103 25	110 80 45	110 75 35	22 sec.	Face, neck	Vivid	Fullness in head. Palpitation. Buzzing in head.
R. Age 38	8.11	Flushes easily. Pulse readily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	142 95 28	110 162 ?	162 120 25	166 90 25	15 sec.	Face Neck Upper chest	Vivid Slight Slight	Fullness in head. Tightness in throat. Palpitation. Diffuse impulse.
L. Age 22	10.11	Does not flush easily. Pulse not easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	 80 26	 115 29	 78 22	 70 22	23 sec.	Face and neck	Vivid	Feeling of heat. Palpitation. Slight headache.
C. Age 35	8.7	Flushes easily. Pulse not easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	152 68 30	110 80 30	150 110 33	150 75 33	49 sec.	Face Neck Chest	Vivid Vivid Reddish mottling	Feeling of heat. Slight giddiness. Slight palpitation. Diffuse impulse.
L. Age 23	11.0	Flushes very easily. Pulse rate easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	136 82 17	100 110 10	132 92 18	132 70 20	26 sec.	Face only	Moderate	Palpitation and giddiness. Headache. Singing in ears.
R. Age 18	9.3	Flushes very easily and intensely. Pulse easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	130 99 25	40 143 24	132 103 27	132 114 25	10 sec.	Face, neck and chest	Vivid purple	Palpitation and giddiness. Limbs and head throb. Fullness in head.
S. Age 19.	10.2	Flushes easily. Pulse not easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	131 93 12	120 110 20	130 66 12	130 66 12	20 sec.	Face, neck	Moderate	Flushing and palpitation. Slight giddiness. Fullness in head.
G. Age 24	11.4	Does not flush easily. Pulse easily accelerated by exercise.	·06 cc.	B. P. Pulse Resps.	110 92 31	80 125 35	110 115 40	110 92 45	25 sec.	Face only	Moderate	Fullness in head. Slight giddiness. Palpitation.
D. Age 27	12.0	Flushes easily and intensely. Pulse not easily accelerated by exercise.	·06 cc.	B. P. Pulse Resps.	116 86 21	80 110 22	100 90 20	116 85 15	23 sec.	Face, neck Upper part of chest	Vivid Slight	Throbbing in head. Slight giddiness. Singing in ears.
B. Age 26	9.3	Does not flush easily. Pulse very easily accelerated by exercise.	·05 cc.	B. P. Pulse Resps.	110 86 35	90 140 24	110 115 19	110 90 25	48 sec.	Face only	Moderate	Giddiness. Slight headache. Slight palpitation.

acceleration with amyl nitrite is also conspicuous ; whereas in those in whom the acceleration upon effort is less decided, the amyl nitrite acceleration is no more than normal.

The time reactions of the flush are similar in the group of patients and in the group of controls ; the drug reaches the peripheral vessels in cases of irritable heart in normal time intervals. It is probable therefore that while these subjects are at rest the rate at which the blood stream flows is normal.

THE PULSE RATE ON STANDING AND ON SLIGHT EXERTION IN HEALTHY MEN AND IN CASES OF "SOLDIER'S HEART."*

By JOHN PARKINSON.

(*From the Military Hospital, Hampstead.*)

Method.

THE subject lay recumbent for fifteen minutes before any observations were made. A polygraph was connected with the wrist and when the rate was constant a reading was taken. The patient, still connected with the polygraph, was told to stand up and the rate was recorded for two minutes. Retaining the wrist attachment, the man was then sent down 25 steps and made to climb them at a moderate walking pace. On his return he was immediately re-connected and a tracing was taken for three minutes, the subject standing. The time lost in attaching the polygraph was not more than a few seconds. After three minutes he was told to lie down again and the final tracing was then taken for two minutes.

The figures were counted on the tracing in six-second periods. The first six seconds after standing and after exertion were considered the *immediate* rate and are so named on the tables. All the other figures are the average of five six-second periods and therefore represent the rate per minute during each half-minute period. The amount of exertion was intentionally made light, so that the change of rate in healthy men and in patients should be suitably contrasted; with severe exertion the rate, even in normal men, would often become quite high.

(*a*) *Healthy soldiers* (controls). From the R.A.M.C. personnel of the hospital were chosen twenty men who did not consider themselves short-winded: sixteen (Nos. 1-16) played in the football team. They had no symptoms or signs of heart disease, and gave no history of acute rheumatism.

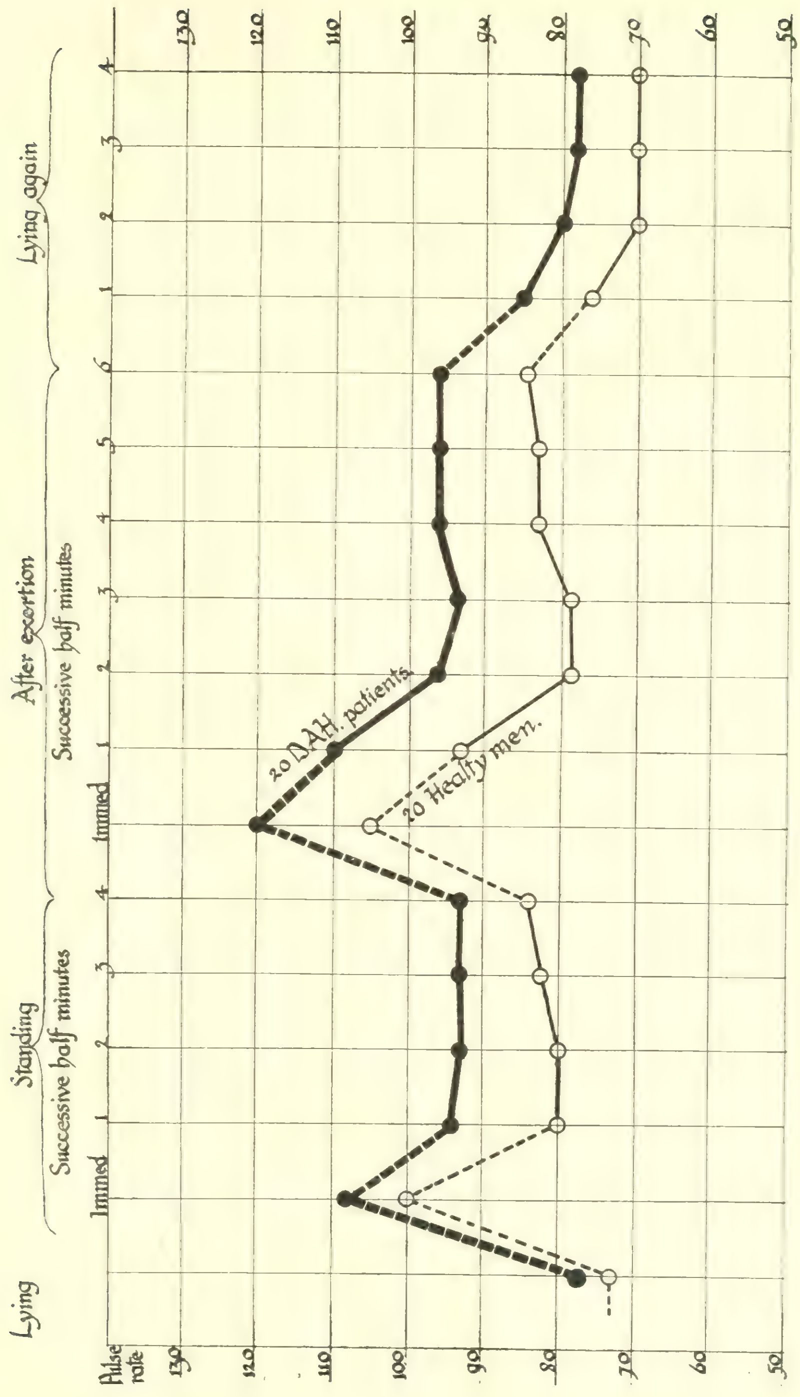
(*b*) *Patients* ("*soldier's heart*"). After excluding patients with valvular or other gross heart lesion, the first twenty patients available were used in these observations. They all complained of breathlessness on exertion and some of precordial pain, palpitation, etc.; but no abnormal signs were found on physical examination.

* Undertaken on behalf of the Medical Research Committee.

No.	Initials.	Lying.	Standing. (Immed.)	Standing. Successive ½ min. periods.				After exertion. (Immed.)	After exertion. Successive ½ min. periods.						Lying again. Successive ½ min. periods.			
1.	F. D.	60	(98)	76	70	75	76	(102)	90	65	72	80	78	78	70	62	63	67
2.	H. F.	73	(83)	74	78	79	86	(95)	88	76	77	80	81	85	80	74	69	70
3.	R. H. P.	78	(86)	82	92	91	92	(101)	91	77	84	87	86	89	74	73	75	73
4.	L. F. A.	70	(90)	71	76	82	76	(87)	79	70	69	76	74	75	80	74	74	68
5.	G. H. C.	83	(109)	96	91	93	91	(125)	109	86	89	96	99	93	95	83	83	81
6.	J. W. C.	61	(83)	67	63	67	68	(79)	71	65	57	58	58	57	62	57	57	58
7.	J. W.	73	(112)	80	93	90	94	(113)	94	78	86	93	94	94	71	69	67	72
8.	A. W. H.	87	(124)	101	78	85	84	(122)	113	97	93	92	90	96	99	85	85	79
9.	P. J. S.	81	(110)	89	92	95	97	(106)	99	96	102	100	90	86	72	63	63	63
10.	F. A.	71	(78)	68	69	72	73	(80)	72	64	70	75	77	78	73	70	67	68
11.	J. W. N.	68	(108)	79	77	69	73	(140)	114	89	76	73	72	79	82	77	77	77
12.	C. H. B.	81	(110)	88	85	87	88	(100)	93	87	93	98	97	99	86	77	84	85
13.	L. B.	74	(95)	77	81	80	87	(120)	102	78	74	77	82	85	72	68	70	67
14.	J. A. L.	80	(120)	89	87	85	82	(130)	120	85	80	84	88	92	92	77	77	77
15.	L. M.	67	(96)	77	79	87	94	(108)	102	95	87	92	91	89	84	78	75	78
16.	T. W.	73	(88)	72	70	72	76	(103)	88	77	70	77	78	80	68	68	67	68
17.	F. O.	71	(93)	76	77	73	76	(103)	97	82	75	77	74	74	70	63	64	63
18.	F. J. E.	68	(112)	87	80	83	81	(102)	71	59	69	86	77	85	67	58	59	54
19.	E. H.	72	(110)	86	86	86	95	(89)	81	75	73	77	85	85	67	64	62	66
20.	R. B. H.	60	(82)	68	74	84	83	(107)	98	75	73	77	81	83	61	54	58	61
	Average	72	(99)	80	80	82	84	(105)	93	78	78	83	83	84	76	70	70	70

TABLE II.—Pulse rate in cases of "soldier's heart" on standing and after exertion.

No.	Initials.	Lying.	Standing. (Immed.)	Standing. Successive ½ min. periods.				After exertion. (Immed.)	After exertion. Successive ½ min. periods.						Lying again. Successive ½ min. periods.				Symptoms produced. Shortness of breath.	Symptoms produced. Other symptoms (slight).
1.	T. A. C.	70	(90)	77	72	66	64	(85)	77	67	69	77	72	79	69	74	66	65	slight	—
2.	G. K.	95	(112)	114	113	116	117	(146)	141	125	115	110	114	116	107	106	102	110	—	pain
3.	G. P.	67	(86)	74	72	75	76	(112)	97	81	86	87	83	87	82	72	68	66	—	—
4.	W. B.	93	(145)	123	106	109	104	(155)	132	115	113	111	111	111	108	98	97	94	—	palpitation
5.	T. S.	59	(105)	78	67	75	72	(110)	81	67	66	78	89	83	75	59	60	59	—	—
6.	A. H.	101	(104)	107	112	118	119	(160)	148	125	121	118	118	117	106	110	103	105	+	palpitation
7.	H. S.	44	(60)	57	58	61	63	(94)	75	59	59	59	62	63	45	45	44	43	—	—
8.	A. F. A.	65	(102)	91	96	94	98	(118)	103	94	97	106	105	89	70	63	61	60	+	palpitation
9.	A. D.	75	(110)	86	93	89	95	(125)	108	87	88	94	86	90	93	78	82	76	—	—
10.	W. McG.	82	(130)	121	114	108	106	(137)	127	111	109	106	109	111	94	78	79	79	slight	—
11.	T. R.	62	(79)	77	77	71	71	(92)	80	69	72	70	71	70	60	57	61	58	+	giddiness
12.	L. J. R.	93	(117)	97	84	85	83	(154)	139	119	105	123	101	99	97	90	89	88	slight	palpitation
13.	L. S. W.	71	(106)	84	80	83	87	(105)	95	80	79	83	82	80	82	79	78	75	slight	giddiness
14.	A. H.	73	(122)	112	115	115	116	(116)	109	100	102	102	105	109	89	74	72	68	—	—
15.	C. G. E.	84	(118)	104	109	107	111	(140)	136	125	119	119	118	117	85	85	83	84	+	palpitation
16.	J. C.	72	(73)	72	81	79	78	(96)	93	86	83	84	88	89	74	71	73	76	+	—
17.	P. A. P.	77	(116)	97	97	89	94	(90)	86	83	81	93	96	94	72	67	70	75	slight	—
18.	W. F. H.	94	(125)	112	112	110	112	(146)	136	121	115	117	115	115	104	93	92	85	slight	—
19.	E. A. L.	87	(137)	109	102	116	103	(134)	124	106	111	98	106	112	93	86	91	86	slight	giddiness
20.	R. C. W.	82	(115)	96	95	90	94	(115)	111	97	92	98	108	105	98	90	89	85	+	—
	Average	77	(108)	94	93	93	93	(121)	110	96	94	97	97	97	85	79	78	77		


Pulse rate
130
120
110
100
90
80
70
60
50
Lying
Standing
Successive half minutes
Immed
1
2
3
4
After exertion
Successive half minutes
Immed
1
2
3
4
5
6
Lying again
1
2
3
4
20 D.A.H. patients
20 Healthy men.

Symptoms after exertion test. Fifteen of the twenty patients showed slight symptoms after the exertion test. (See Table II.) In those who became objectively short of breath, this is indicated by the sign + in that table. None of the controls showed breathlessness on the test.

Results.

(*a*) *Controls.* The figures obtained are shown in Table I. The average rate, with the subject recumbent, was 72 a minute. The immediate rate after rising (the first six seconds) was 99, but this was largely due to the *exertion* of rising. The true average rate while standing was 82, an increase of 10 beats a minute. Similarly the immediate rate after exertion was 105, but the average rate for the first half-minute after exertion was 93, an increase of 11 beats over the rate standing. A half to one minute later, the original standing rate was regained.

(*b*). *Patients.* The figures are shown in Table II. The average rate, lying, was 77, *i.e.*, 5 higher than the controls. It increased momentarily to 108 on standing, but the average rate standing was 93, an increase of 16 beats. After exertion it increased to 121 for six seconds ; the average for the first half-minute was 110, an increase over standing of 17. In half to one minute the rate had almost returned to that on standing. On lying again the rate dropped in half a minute to the original lying rate.

Summary of Results. (See Chart.)

The average pulse rate in twenty consecutive D. A. H. patients ("soldier's heart") was 77, only five beats higher than that of twenty healthy controls. The average increase in rate on standing and after exertion was greater in these patients than in the controls. The average pulse rate after slight exertion returned to the previous standing rate within a half to one minute both in patients and in controls, though scarcely so completely in the former. Individual variations are indicated in the tables.

DIGITALIS IN SOLDIERS WITH CARDIAC SYMPTOMS AND A FREQUENT PULSE.*

By JOHN PARKINSON.

(*From the Military Hospital, Hampstead.*)

Among soldiers who report sick complaining of cardiac symptoms and especially of undue breathlessness on exertion, we find a large proportion in whom no abnormal physical signs are discoverable. The signs of valvular disease are absent and the heart is not enlarged. These cases have been described under the terms " irritable heart " and " soldier's heart," though in a large number of them the disability has existed long before enlistment.

It is widely believed that these patients as a class have a heart rate which is much higher than that of normal men. As a matter of fact the collected records of such cases show an average rate, when recumbent, only a few beats higher than normal. Thus the average among forty patients recently reported was 75 per minute, and in only three of these was it higher than 90[1]. In a later series of forty consecutive cases where the rate was ascertained by polygraph, and after they had been recumbent for fifteen minutes, the average rate was 78·5, only 6·5 beats higher than the average rate (72) found in twenty healthy soldiers by the same method. The increase of rate on standing and on exertion is greater among these patients than in normal men, though the contrast is not so remarkable as might have been supposed.[2]

A number of these patients do, however, show a high pulse rate and one which decreases little or not at all after rest in bed. If any group of patients among those classified as " irritable heart of soldiers " might be expected to benefit from digitalis, this is the group. The present inquiry was undertaken to determine whether in such cases a course of digitalis (1) relieves the symptoms, (2) reduces the rate of the heart, or (3) controls the increased rate on standing and on exertion.

It proved difficult to find a sufficient number of patients for this purpose even among 150 beds set aside for heart cases. Though many were admitted with a pulse rate above the normal, the majority of these became normal

* Undertaken on behalf of the Medical Research Committee.

after two or three days in bed, and so were unsuitable for observations on this point. In course of time twenty men were obtained whose pulse rate in hospital persisted at 80-110 per minute while recumbent. The temperature was in each case normal. They all complained of breathlessness on moderate exertion and observation showed that they were unduly breathless after exertion. Other symptoms are indicated in the clinical summaries appended. No abnormal physical signs could be found except the frequent heart action. Polygraphic or electrocardiographic records showed that the rhythm was normal. The apex beat was felt in the fifth left interspace, internal to the nipple line, and with one exception no murmurs were heard.

In five of the twenty cases there was a history of acute rheumatism, from which the symptoms dated. In four other cases the symptoms followed enteric fever, dysentery, cystitis, and "influenza," respectively. In one patient the thyroid gland became enlarged later. Three patients were nervous in their manner ; the symptoms in one of these had been aggravated by shell shock. In the remaining seven patients the cause of the disability was not discovered. In nine of the twenty cases the symptoms had been present for years before enlistment. A short summary of each case is appended. It is noteworthy that only five of these patients returned to light duty, while the remaining fifteen were discharged from the army as permanently unfit.

The first eight patients obtained were investigated by a certain routine method and polygraphic counts were made ; they are classed as Series I. Subsequently twelve more patients were observed by a modified method and they are classed as Series II.

Series I. (*CASES* 1-8.)

Method of observation.

As most of the patients had been in bed for long periods without relief before admission and showed no reduction in pulse rate after a week or more in bed at this hospital, they were allowed up. Polygraphic records of pulse rate and respiration rate were then taken daily at the same time of day, when they had been recumbent for ten minutes. The blood pressure was estimated by a Riva-Rocci mercurial sphygmomanometer (Martin's modification). A reading of the systolic pressure was first obtained by palpation and then by auscultation. The point at which the sounds suddenly become soft and scarcely audible was used as the measure of diastolic pressure, not the point where they entirely disappear.[3] When these observations had been recorded for seven consecutive days the course of digitalis was started. Twenty minims of tincture of digitalis, B. P., were administered three times

a day in *CASES* 3-8, fifteen minims in *CASES* 1 and 2, and continued for fourteen days unless symptoms of digitalis excess appeared. The daily observations were maintained during this period and for a week after the digitalis had been stopped. The tincture, prepared and physiologically standardised by Parke Davis and Company, was active, for it converted the abnormal rhythm of a patient with auricular flutter into auricular fibrillation and thence into the normal rhythm, when used in similar doses.

In addition to the instrumental observations, attention was paid particularly to the effect of digitalis upon the patients' symptoms. As these are naturally difficult to gauge, an *exertion test* was employed (1) before digitalis, (2) after 7 drachms, and (3) after 14 drachms of the tincture. The details of this test will be found below under the section on the effect of standing and of exertion on the rate.

Effect on heart rate at rest.

The average reduction in rate was slight and is shown in Table I. Taking the average in the week before digitalis and comparing it with the average during the period of administration or with that of the week following its withdrawal, we find the pulse rate reduced by no more than three beats or four beats respectively. In not a single case in this series was the average rate under digitalis reduced by more than nine beats. Moreover, in three cases the average rate was increased.

A more exact estimate of the digitalis effect will be obtained from Fig. 1. In the week before digitalis the rate varied from 89 to 95; during the twelve days of digitalis the rate was 84-92, and in the week after it had been stopped it was 85-88. As the rate remained fairly constant in the first week of observation and the first few days of digitalis, the slight fall which occurred may be considered as due to the drug, though the lapse of time alone may have assisted. Thus among these patients the reduction in rate produced by digitalis in full doses was almost negligible.

The effect on the increase of rate produced by standing and by exertion.

A simple exertion test was applied (1) before the course of digitalis, (2) after 7 drachms of tincture had been taken, and (3) after 14 drachms.

The test applied was as follows. After the patient had been recumbent for fifteen minutes a polygraph was applied to the wrist and a reading taken. Still connected with the instrument, he was told to stand up and the change in rate was recorded for two minutes. Retaining the wrist attachment,

the man was next sent down 25 steps and made to climb them quickly; walking in *CASES* 1-4, running in *CASES* 5-10. On his return the wrist attachment was immediately re-connected and a tracing was taken for three minutes. The time lost in attaching the polygraph was not more than a few seconds. After three minutes, during which the patient stood, he was made to lie down and the final tracing was taken for two minutes.

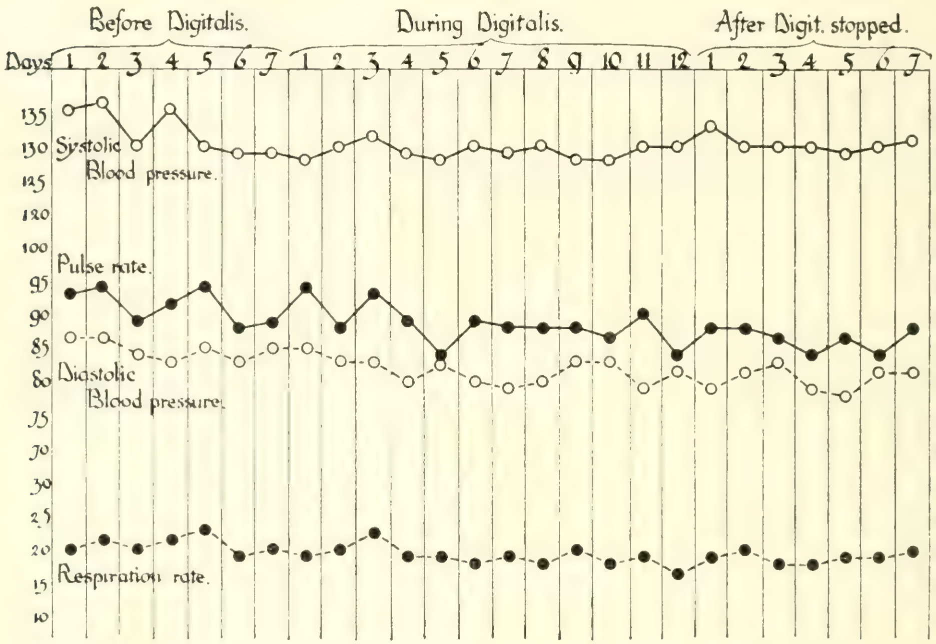


Fig. 1. Effect of digitalis in patients with high pulse rate (Cases 1–8).

The figures were counted on the tracing in six-second periods. The first six-second period after standing and after exertion was considered the *immediate* rate and is so named in Tables III (*a*) (*b*). All the other figures are the average of five six-second periods, and therefore represent the rate per minute during each half-minute period.

Apart from these observations on rate, attention was directed at every exertion test to the degree of breathlessness induced thereby. Any objective distress was noted as well as the patient's own sensations, as soon as he had climbed the stairs.

The combined results of these tests are tabulated in Tables III (*a*) (*b*) and depicted in Fig. 2. The curve of exertion under digitalis is the mean of the two curves obtained after 7 and after 14 drachms respectively;

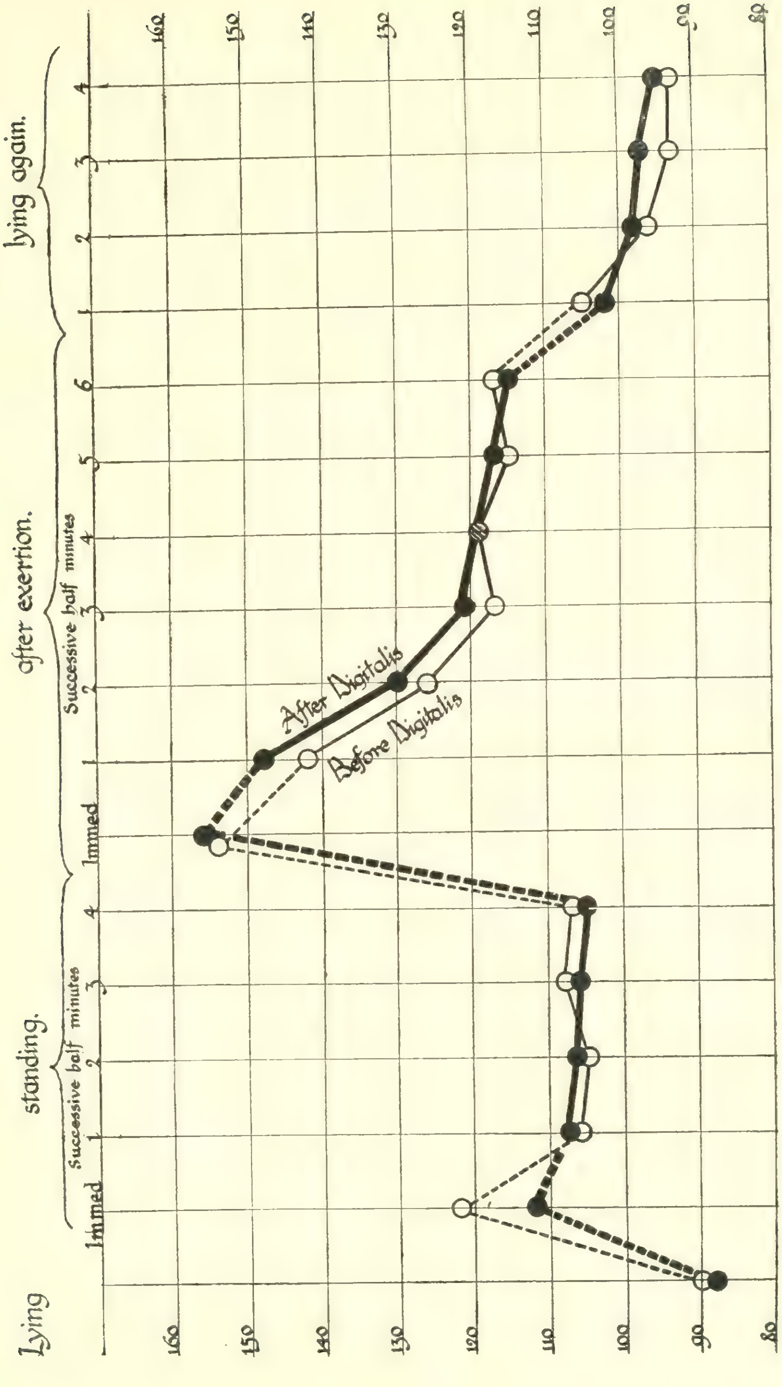


Fig. 2. Pulse rate on standing and on exertion before and after digitalis in ten patients with high pulse rate (Cases 1–10).

there was little difference between the two. The curve obtained before the administration of digitalis in the ten patients (*CASES* 9 and 10 are included) is very similar to that obtained when these patients were under the influence of digitalis. The only difference is the slight limitation of increase in rate immediately on standing, *i.e.*, the first six seconds. Against this apparent advantage, if such it be, may be placed an apparent failure of the pulse rate to fall so quickly after exertion when the patients were under digitalis. Briefly, the chart shows that digitalis fails to control the increase of rate on standing and after exertion in these patients to any appreciable extent.

Effect on respiratory rate.

The average rate of respiration was little affected by the drug. (See Table I and Fig. 1.) In *CASE* 3, a patient who had two attacks of angina pectoris before digitalis was begun, the rate was considerably reduced—34 per minute became 21 during the period of administration. Yet the pulse rate in this patient was increased rather than decreased during the same period. In *CASE* 7 also the rate of respiration fell, though to a less extent.

Effect on blood pressure.

The blood pressure, systolic and diastolic, was quite unaffected. (Table I, Fig. 1.) It is now generally recognised that digitalis in medicinal doses does not raise systolic blood pressure. It appears that diastolic pressure is equally unaffected and consequently the so-called "pulse pressure"—the difference between systolic and diastolic readings—shows no change.

The figures of systolic pressure are those obtained by auscultation; the palpatory method was also used at every observation and in an average of 215 readings proved to be 129 mm. Hg., *i.e.*, 3 mm. less than the average of the same number of readings by the auscultatory method (132 mm.). The latter method is quite as reliable as the palpatory and more convenient when the diastolic pressure is also to be estimated.

Effect on symptoms.

(*a*) *Symptoms induced by the exertion test.* The degree of breathlessness evoked by the exertion test *before* digitalis was compared with the degree of breathlessness at the subsequent tests when the patient had taken 7 and 14 drachms of digitalis tincture. Every patient said he was breathless (subjective) after climbing the 25 steps; and every one appeared breathless (objective). In six cases the breathlessness after exertion, both subjective and objective, was of the same degree during digitalis as before it was given. In three patients (*CASES* 2, 3, 5) the breathlessness when under digitalis

was said to be greater than before it, and judged objectively this appeared true. One patient only, *CASE* 6, claimed to be less breathless after the two exertion tests performed while he was taking digitalis, and he did appear less breathless on these occasions. In all, therefore, six cases were uninfluenced, three showed more breathlessness on digitalis, and one showed less. Digitalis, therefore, failed to reduce breathlessness on exertion in these patients.

(*b*) *General condition.* From time to time during the course of digitalis an attempt was made to ascertain whether the patient felt better generally or in respect of any of his symptoms, as he walked about the garden and neighbourhood. We asked his opinion and indicated that we were indifferent as to what the opinion might be. Only one patient, *CASE* 6, the man referred to above, claimed and really appeared to be improved and not so breathless when walking about. The others, and they were reliable men, claimed to be unaffected in these respects.

(*c*) *Symptoms referable to digitalis* (*CASES* 1-8). *CASES* 2, 5, 6 and 7 showed no symptoms of digitalis intoxication. *CASES* 1 and 8 complained of headache after 4 and 10 drachms, respectively, though it was not sufficiently severe to require its discontinuance. *CASE* 4 mentioned slight nausea after 8 drachms had been taken. In *CASE* 3 no symptoms resulted from the digitalis administration, but after 5 drachms had been taken a slight grade of auriculo-ventricular heart-block was produced, accompanied by an irregularity which proved to be sino-auricular block. (See Appendix 2 and Fig. 4.)

Series II. (*CASES* 9-20.)

The twelve patients here considered have been separated from those in Series I because the daily counts of pulse rate were made by palpation and not instrumentally. In all other respects the same precautions were taken as in Series I, while attention was specially centred on (*a*) the pulse rate whilst lying, on standing, and after exertion ; and on (*b*) the symptoms produced by test exertion.

Each man came daily at the same time and lay on the bed for ten minutes, after which the pulse rate was counted for a half-minute. The man then stood up and after one minute the pulse was again counted. Every other day he was made to run up 25 steps (the exertion test) and the half-minute count immediately taken was recorded as the immediate rate after exertion. His subjective and objective breathlessness was noted. When these records had been taken for nine days the course of digitalis was commenced, viz., tincture of digitalis, B. P., twenty minims three times a day for fourteen days, exactly as in Series I. The observations were continued in the same fashion as before digitalis was given. The results are given in Table II and Fig. 3.

Pulse rate.

(*a*) *Lying.* The average rate before digitalis was 95, during the course 86, a fall of nine beats per minute. The individual variations are seen in Table II and the daily variations in Fig. 3. The decrease was most evident in *CASES* 16 and 20, where the rate fell by 20 beats.

(*b*) *Standing.* The average rate while standing was not affected so much as the recumbent rate; the average decrease was but three beats. (Table II, Fig. 3.) *CASES* 17 and 20 were most affected.

(*c*) *After exertion.* The average rate after exertion was reduced merely by eight beats during the course of digitalis. The individual changes are shown in Table II.

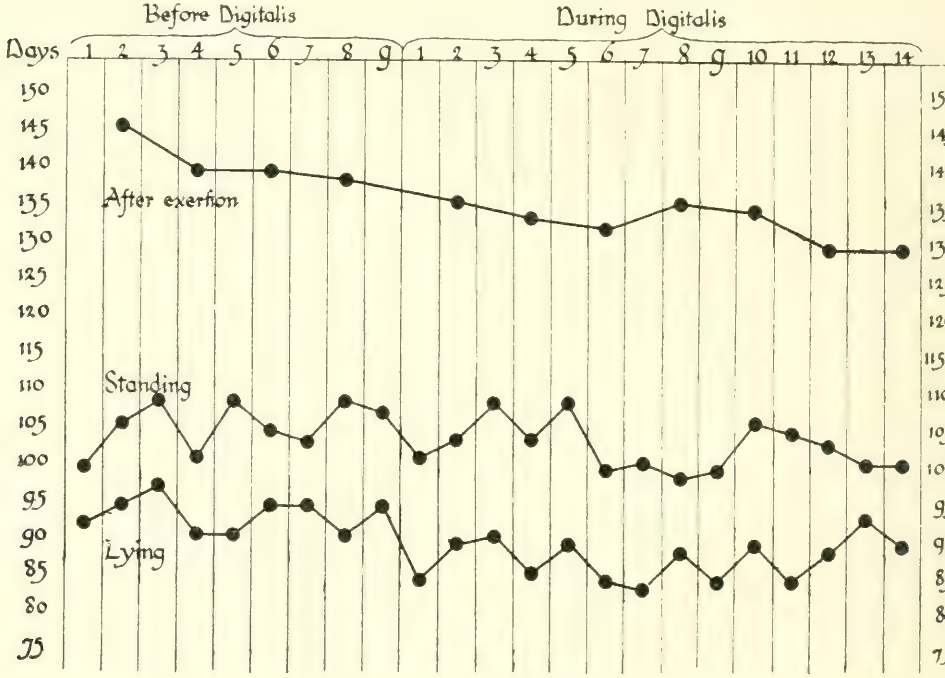


Fig 3. The pulse rate before and during the course of digitalis (12 Cases).

Symptoms on exertion.

A note on the breathlessness (subjective and objective) induced by the exertion test in each patient was made every other day. Of these twelve patients, ten showed no improvement—they felt and looked quite as short of breath after the exertion tests while taking digitalis as they did before. In *CASE* 19 there was moderate improvement, in that he felt and looked

TABLE I.

EFFECT OF DIGITALIS IN EIGHT SOLDIERS WITH CARDIAC SYMPTOMS AND A FREQUENT PULSE.
(*CASES* 1-8, *i.e.*, *Series* I.)

No.	Initials.	Course of Tinct. Digitalis.	Pulse rate.			Respiration rate.			Systolic blood pressure.			Diastolic blood pressure.		
			Week before.	During digitalis.	Week after.	Week before.	During digitalis.	Week after.	Week before.	During digitalis.	Week after.	Week before.	During digitalis.	Week after.
1.	L. J. R.	8 drachms in 11 days	89	91	93	24	23	24	140	137	138	79	80	77
2.	J. H. S.	8 „ 11 „	81	88	80	30	30	29	128	128	125	77	75	76
3.	J. H.	13 „ 16 „	91	93	83	34	21	20	130	133	132	82	81	80
4.	G. F. S.	12 „ 12 „	92	86	87	17	18	20	121	122	121	78	81	77
5.	J. H. B.	14 „ 14 „	87	83	82	19	19	16	122	124	127	89	80	80
6.	A. E. C.	14 „ 14 „	96	87	85	13	15	15	132	129	129	90	84	87
7.	L. J. W.	14 „ 14 „	114	106	100	24	17	17	155	149	150	98	92	97
8.	H. R. C.	14 „ 14 „	83	78	91	17	19	19	128	126	127	87	88	83
	Average	12 drachms in 13 days	92	89	88	22	20	20	132	131	131	85	83	82

TABLE II.

(*CASES* 9-20, *i.e., Series* II.)

AVERAGE PULSE RATE BEFORE AND DURING COURSE OF DIGITALIS.

(14 drachms of tincture in 14 days.)

No.	Initials.	Lying.		Standing.		After exertion.	
		Before digitalis.	During digitalis.	Before digitalis.	During digitalis.	Before digitalis.	During digitalis.
9.	S. C. W.	91	86	99	100	144	143
10.	W. I.	86	82	91	92	141	127
11.	H. Z.	102	86	115	110	154	148
12.	R. A.	82	74	89	89	142	133
13.	J. K.	90	77	102	89	136	122
14.	H. W.	76	68	91	87	113	116
15.	J. E. P.	89	85	102	99	132	127
16.	L. E.	113	93	120	112	149	133
17.	J. E.	110	93	116	102	144	129
18.	D. B.	84	95	92	118	142	144
19.	E. W.	97	100	106	107	142	132
20.	J. C.	115	95	141	124	150	145
	Average	95	86	105	102	141	133

TABLE III.

EXERTION TESTS, BEFORE AND AFTER DIGITALIS.

(Soldiers with cardiac symptoms and rapid pulse rate.)

(*a*). BEFORE DIGITALIS.

No.	Initials.	LYING.	STANDING. (Immed.)	STANDING. Successive ½ min. periods.				AFTER EXERTION. (Immed.)	AFTER EXERTION. Successive ½ min. periods.						LYING AGAIN. Successive ½ min. periods.			
1.	L. T. R.	93	(117)	97	84	85	83	(154)	139	119	105	123	101	99	97	90	89	88
2.	J. H. S.	76	(123)	92	96	103	103	(152)	139	122	123	131	117	115	97	83	87	89
3.	J. H.	93	(104)	92	90	99	106	(158)	149	140	122	121	120	120	101	94	88	86
4.	G. F. S.	81	(118)	98	100	99	97	(115)	107	98	89	96	103	105	89	91	92	88
5.	J. H. B.	84	(130)	117	111	116	110	(170)	156	133	125	119	112	115	106	97	89	96
6.	A. E. C.	90	(120)	98	95	103	107	(150)	128	109	108	103	102	122	107	99	99	99
7.	L. J. W.	117	(152)	146	143	139	146	(180)	174	171	162	160	156	152	137	126	121	121
8.	H. R. C.	92	(120)	125	128	134	116	(166)	160	145	129	129	131	131	95	91	91	82
9.	S. C. W.	95	(122)	118	114	110	106	(150)	139	123	114	115	114	112	110	103	96	96
10.	W. I.	83	(115)	91	93	94	94	(142)	130	99	92	97	95	95	100	91	88	84
	Average	90	(122)	106	105	108	107	(154)	142	126	117	119	115	117	105	96	93	93

TABLE III—(*continued*).

(*b*). AFTER DIGITALIS.

No.	Initials.	After tinct. digitalis.	Lying.	Standing. (Immed.)	Standing. Successive ½ min. periods.				After exertion. (Immed.)	After exertion. Successive ½ min. periods.						Lying again. Successive ½ min. periods.				Breathlessness induced by exertion test. Before digitalis	After digitalis.
		drachms																			
1.	L. T. R.	(*a*) 6	88	(75)	82	81	87	85	(155)	148	129	125	115	107	102	87	85	89	85	moderate	moderate
		(*b*) 8	89	(120)	94	79	82	81	(144)	133	110	96	99	96	90	96	89	83	80	moderate	moderate
2.	J. H. S.	8	87	(84)	88	95	104	100	(162)	143	129	123	125	120	115	95	92	95	92	moderate	increased
3.	J. H.	12	102	(128)	110	116	115	112	(162)	159	149	140	142	135	137	123	112	111	106	severe	increased
4.	G. F. S.	(*a*) 9	86	(95)	86	93	95	95	(102)	103	96	91	103	102	99	88	88	87	86	severe	severe
		(*b*) 12	100	(120)	119	120	119	120	(145)	136	127	120	118	121	120	100	98	105	101	severe	severe
5.	J. H. B.	(*a*) 5½	86	(116)	125	129	119	111	(170)	163	148	141	126	129	125	112	107	103	99	moderate	increased
		(*b*) 14	79	(125)	124	128	119	106	(185)	175	158	141	135	136	123	111	108	104	107	moderate	increased
6.	A. E. C.	(*a*) 6½	100	(120)	111	112	109	116	(168)	154	125	127	121	123	127	102	100	103	104	moderate	decreased
		(*b*) 14	78	(108)	101	100	95	94	(166)	150	127	114	108	114	108	98	92	91	90	moderate	decreased
7.	L. J. W.	(*a*) 6½	108	(140)	129	124	123	125	(170)	161	148	141	144	140	140	125	121	118	117	moderate	moderate
		(*b*) 14	106	(138)	136	134	127	129	(178)	162	150	136	134	131	132	120	112	114	108	moderate	moderate
8.	H. R. C.	(*a*) 5½	80	(120)	129	139	138	133	(160)	157	148	133	129	135	133	87	76	74	69	moderate	moderate
		(*b*) 14	84	(98)	108	107	100	105	(183)	180	162	149	147	134	139	115	114	103	104	moderate	moderate
9.	S. C. W.	(*a*) 7	78	(100)	96	92	87	88	(150)	138	109	105	105	99	96	96	91	93	89	moderate	moderate
		(*b*) 14	88	(108)	97	90	90	93	(132)	120	103	102	103	98	98	89	87	90	88	moderate	moderate
10.	W. I.	(*a*) 7	68	(104)	90	90	90	92	(124)	120	95	86	86	91	90	84	82	78	78	moderate	moderate
		(*b*) 13	84	(112)	106	102	100	96	(160)	149	128	101	105	101	103	101	90	90	89	moderate	moderate
	Average		89	(112)	107	106	106	105	(156)	148	130	121	119	117	115	102	98	97	94		

less breathless after exertion when he had taken 4 drachms of digitalis tincture and for the remainder of the course. *CASE* 20, the patient whose pulse rate was notably decreased, felt steadier and was not so much troubled by palpitation when he was taking digitalis, though his breathlessness was scarcely improved. Yet four days after digitalis was stopped the rate had risen to 108, and the symptoms had increased again. This man was given another course of digitalis at his own request, and again the pulse decreased in rate and the palpitation and shakiness improved.

Three of the twelve patients in Series II complained of slight headache, one also of nausea, after 6 or more drachms of digitalis. The remainder showed no toxic symptoms.

Summary.

Digitalis in full doses was exhibited in twenty soldiers with cardiac symptoms and a frequent pulse ; the heart rhythm was normal. The rate of the heart was reduced but little ; the increase in rate produced by standing and by exertion was not controlled to any appreciable extent. The systolic and diastolic blood pressure was unaffected. Further, the degree of breathlessness induced by test exertion was not reduced by the drug. It is concluded that digitalis scarcely influences the group of patients classified as " soldier's heart " or " irritable heart," even when the pulse is frequent, and that it is not indicated in this condition.

An example of sino-auricular block due to digitalis is described in the second appendix.

References.

[1] Parkinson. *Lancet,* 1916, ii, 133.

[2] Parkinson. *Heart,* 1917, vi, 317.

[3] MacWilliam and Melvin. *Heart,* 1913-14, v, 153.

APPENDIX 1. Clinical Summaries.

(*No abnormal physical signs were detected except where stated.*)

CASE 1. L. J. R., 49693, aged 28. Age 13, acute rheumatism; breathlessness on exertion, especially since enlistment.

CASE 2. J. H. S., 2804, aged 21. Always short-winded; more breathless on exertion since enlistment. A month after course of digitalis thyroid gland enlarged, hence tachycardia probably due to hyperthyroidism.

CASE 3. J. H., 1356, aged 35. Age 21, enteric fever; age 26, acute rheumatism, short-winded since. Breathlessness and weakness on exertion since enlistment. No signs of cardiac enlargement, first sound scarcely audible at any area, no murmurs. Wassermann reaction positive. While in hospital two attacks of angina pectoris, one before and another two days after commencing course of digitalis; none during following four weeks of observation.

CASE 4. G. F. S., 10188, aged 39. Since enlistment giddiness and breathlessness on exertion.

CASE 5. J. H. B., 15986, aged 21. Palpitation and breathlessness on exertion followed exposure and long marches in Mesopotamia.

CASE 6. A. E. C., 1985, aged 23. Six months ago, enteric fever; breathlessness on exertion since.

CASE 7. L. J. W., 158571, aged 29. Always breathless on exertion, worse since enlistment.

CASE 8. H. R. C., 2731, aged 20. Age 16, acute rheumatism, followed by breathlessness on exertion, especially since shell shock four months ago. On examination: nervous manner, facial tic; no other abnormal signs except frequent pulse.

CASE 9. S. C. W., 2035, aged 19 Giddiness and weakness on exertion.

CASE 10. W. I., 14943, aged 21. Age 11, acute rheumatism. Acute rheumatism, second attack, nine months ago; breathlessness on exertion worse since, also precordial pain. On examination: localised systolic murmur at apex, scarcely audible on standing. No signs of enlargement.

CASE 11. H. Z., 18022, aged 29. Breathlessness and palpitation on exertion for many years before enlistment.

CASE 12. R. A., 2688, aged 19. Breathlessness and palpitation followed six months' trench work in France.

CASE 13. J. K., 13299, aged 32. Age 22, discharged from militia for palpitation and nervousness. After six months in France, "influenza" was followed by a return of these symptoms. On examination: nervous; no other abnormal physical signs except frequent pulse.

CASE 14. H. W., 14348, aged 27. Quite well until dysentery at Gallipoli a year ago, followed by breathlessness and precordial pain on exertion.

CASE 15. J. E. P., 3210, aged 30. Palpitation and breathlessness followed cystitis while on active service. No abnormal signs, no signs of urinary disease.

CASE 16. L. E., 4705, aged 20. Palpitation, giddiness and breathlessness before enlistment and worse since. Poor physique, no other abnormal signs.

CASE 17. J. E., 78598, aged 27. Gradual development of dizziness, precordial pain, palpitation, and breathlessness while in France. On examination: nervousness, no other abnormal signs.

CASE 18. D. B., 2145, aged 21. Age 17, acute rheumatism, followed by breathlessness and palpitation on exertion, worse since enlistment.

CASE 19. E. W., 67039, aged 31. Breathlessness on exertion since enlistment, lately accompanied by palpitation.

CASE 20. J. C., 18821, aged 26. Unduly breathless on exertion for years. Precordial pain, giddiness, palpitation, and breathlessness on exertion present during training, worse since service in Gallipoli.

APPENDIX 2.

Note on sino-auricular block produced by digitalis.

The pauses in the radial pulse of *CASE* 3 were shown by polygraphic and electrocardiographic examination to be due to sino-auricular block (Fig. 4). They appeared after 5 drachms of tincture of digitalis had been taken and were accompanied by a slight prolongation of the *a.c.* interval. The *S.-A.* block persisted for five days while the dose of 1 drachm daily was continued, but disappeared after four more days of ½-drachm doses and while this dose was

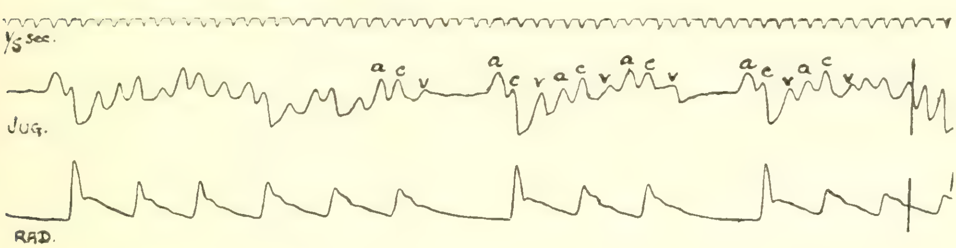


Fig. 4

continued. While the *S.-A.* block was present, it appeared only occasionally on the polygraphic tracing when the patient was recumbent. Deep breathing or sitting up in bed increased its frequency. The exertion of standing up invariably induced it. Pressure on the right and left eyeballs and on the right and left vagus in the neck had no effect upon its frequency. Atropin first increased and later abolished the *S.-A.* block, as shown in the accompanying table.

EFFECT OF ATROPIN IN ABOLISHING SINO-AURICULAR BLOCK.

TIME.	PULSE RATE.	A.C. INTERVAL.	DROPPED BEATS.	
Before	76	1/5+sec.	occas.	
inj.	*atropin sul*	*ph. gr.* 1/50	*subcut.*	
After Mins. 5	78	—	occas.	
10	80	1/5+sec.	v. frequent	Mouth dry.
15	75	—	occas.	
20	82	—	*absent*	Pupils dilated.
25	84	1/5 sec.	*absent*	
30	88	—	*absent*	Deep breathing and even standing now failed to elicit *S.-A.* block.

THE *P-R* INTERVAL BEFORE AND AFTER EXERCISE IN CASES OF "SOLDIER'S HEART."*

By JOHN PARKINSON and A. N. DRURY.

(*From the Military Hospital, Hampstead.*)

It is a well known fact that in instances of myocardial impairment by disease, the auriculo-ventricular bundle may be affected; especially is this the case in instances of rheumatic heart disease. In investigating the pathology of the "irritable heart of soldiers" we have kept constantly before us the possibility that many of these patients in reality present the earliest signs of myocardial involvement, a possibility suggested to us by the frequent history of acute rheumatism amongst these patients. It was important to note therefore whether heart-block in any degree is a frequent manifestation amongst such patients. In our service and in the remaining services of the hospital, heart-block has not been noted with any frequency; it has been seen in a few patients in whom other signs of organic heart mischief were clearly present.

It seemed desirable to test a series of patients more rigidly from the same point of view. In many patients who present frank signs of organic heart trouble, heart-block may not be shown in ordinary circumstances, but in those in whom there is the proclivity, exercise heightens a latent weakness in the function of the conducting tract. In patients in whom there is a defect of conduction, the *immediate* effect of exercise is to decrease the apparent degree of the defect; that is to say, heart-block present before exercise is decreased during and immediately after exertion; but as the rate falls after exercise, the impairment of conducting is most prominent and high grades of heart-block are often encountered.[1-4]

This increase is due in all probability to an increase in vagal tone at the time when the pulse rate falls. When after exertion and during the period of decreased pulse rate which follows it, the conduction interval is normal, there is presumptive evidence of a normal reserve in the functions of the *A-V* bundle. In testing soldiers who suffer from "soldier's heart" we have chosen for this purpose those in whom there has been a past history

* Undertaken on behalf of the Medical Research Committee.

of rheumatic fever; for it is in these that a conduction defect might be expected to show itself more especially. Our observations in ten cases are tabulated in Table I. The heart rate and the *P-R* interval were recorded electrocardiographically before exercise, immediately and for ten minutes after exertion, consisting of skipping for half to one minute. The exercise was so arranged in individual cases that a conspicuous increase of pulse rate (to 128 or 170 per minute) resulted. The *P-R* intervals were measured with accuracy by means of a comparator. As a result of exercise the average heart rate rose from 82 to 152 beats per minute; the *P-R* interval shortened from 0·154 to 0·123 second. At the end of two minutes the interval had recovered to 0·158, in the neighbourhood of which it remained during the ten minutes of observation. As in the average, so in separate individuals there was no appreciable increase of the interval during the period of slowing. Neither defect in conduction, nor a lack of normal reserve in this function, was demonstrable in this series of patients; such variations as were observed in the intervals were within the limits of normal variation.[2]

The *immediate* response of the interval to exercise was tested in a fuller series of similar cases (Table II) and the usual reduction of the interval was found.* In a third series (Table III) of patients in whom high pulse rate while at rest was the rule and in whom digitalis was administered in full doses, the immediate reaction of the *P-R* interval to exercise was similarly tested; in these patients also the interval showed the usual shortening on exertion, and this shortening was unaffected by courses of the tincture, amounting in total dose to 7 drachms and 14 drachms (at the rate of 1 drachm daily).

We are greatly indebted to Dr. Lewis for his advice in these observations.

Summary.

1. Soldiers who suffer from "irritable heart" do not present heart-block with unusual frequency. Even in those who give a history of acute rheumatism, *A-V* conduction, as tested by the response of the *P-R* intervals to exercise, shows a normal reserve.

2. The immediate reaction of the *P-R* interval to exercise in soldiers suffering from irritable heart is a natural shortening; this statement applies both to patients who have been affected by rheumatic fever, and to

* In this series and in the third the exercise consisted in running quickly up 50-70 steps.

TABLE I. *P-R* INTERVAL AFTER EXERTION.

(Ten patients with history of acute rheumatism.)

No.	Initials.	Present age.	Acute rheumatism at age of	Before exertion.		0-½ min. after exertion.		2 min. after exertion.		5 min. after exertion.		8 min. after exertion.		10 min. after exertion.	
				Rate.	P-R.	Rate.	P-R.	Rate.	P-R.	Rate.	P-R.	Rate.	P-R.	Rate.	P-R.
					(sec.)										
1.	G. O. J.	18	15	78	0·158	152	0·125	90	0·157	86	0·170	80	0·179	82	0·167
2.	A. L. F.	33	33	100	0·139	166	0·104	120	0·141	96	0·144	104	0·143	94	0·151
3.	W. I.	21	11 & 20	66	0·201	160	0·127	90	0·180	84	0·196	84	0·191	86	0·188
4.	J. A. J.	17	6	86	0·121	170	0·112	92	0·150	94	0·134	88	0·135	80	0·138
5.	E. J. H.	33	10	76	0·155	144	0·121	102	0·149	90	0·152	84	0·144	84	0·172
6.	C. A. G.	22	22	70	0·166	160	0·135	106	0·163	100	0·154	100	0·165	94	0·173
7.	F. R.	26	14	62	0·150	140	0·125	90	0·185	76	0·160	80	0·167	82	0·174
8.	A. G.	39	14	84	0·148	128	0·141	84	0·161	82	0·161	86	0·163	84	0·159
9.	V. C. W.	20	16	94	0·119	156	0·108	120	0·119	116	0·120	108	0·111	106	0·116
10.	G. S.	23	17	104	0·183	148	0·135	114	0·180	114	0·167	108	0·183	106	0·180
	Average			82	0·154	152	0·123	101	0·158	94	0·156	92	0·158	90	0·162

TABLE II.

EFFECT OF EXERTION ON *P-R* INTERVAL IN TWENTY PATIENTS WITH HISTORY OF ACUTE RHEUMATISM.

No.	Initials.	Age.	Acute rheumatism (years ago).	Rate on exertion.			P-R. interval.		
				Before.	After.	Increase.	Before.	After.	Change.
1.	I. S. W.	32	5 years and $\frac{6}{12}$ year	66	116	50	·150	·132	—·018
2.	G. P.	27	17 years	84	147	63	·159	·125	—·034
3.	W. H.	17	7 years	78	160	82	·144	·103	—·041
4.	C. C.	18	$1\frac{1}{2}$ years	90	144	54	·148	·131	—·017
5.	H. R. C.	20	4 years	100	174	74	·123	·105	—·018
6.	C. A. G.	22	$\frac{2}{12}$ year	110	160	50	·151	·138	—·013
7.	W. I.	21	10 years and 1 year	90	178	88	·187	·139	—·048
8.	E. J. T.	26	10 years and 2 years	54	126	72	·133	·120	—·013
9.	A. S.	19	1 year	80	135	55	·140	·136	—·004
10.	J. S.	40	8, 6, 3 years	96	162	66	·160	·128	—·032
11.	C. B.	22	6 years and $\frac{1}{2}$ year	64	118	54	·128	·105	—·023
12.	G. C. M.	20	4 years	60	130	70	·163	·141	—·022
13.	G. F. C.	22	1 year	80	150	70	·152	·131	—·021
14.	H. B.	18	$\frac{5}{12}$ year	104	174	70	·137	·123	—·014
15.	W. J. A.	19	$\frac{7}{12}$ year	80	150	70	·122	·110	—·012
16.	J. B.	23	5 years	96	176	80	·132	·118	—·014
17.	C. W.	37	$\frac{5}{12}$ year	90	160	70	·164	·146	—·018
18.	E. F.	22	13 years	78	146	68	·138	·140	+·002
19.	F. P.	32	1 year	98	148	50	·153	·146	—·007
20.	F. W. S.	20	$\frac{7}{12}$ year	114	160	46	·160	·131	—·029
	Average	24		86	151	65	·147	·127	—·020

NOTES: 1. The patients were twenty consecutive men presenting cardiac symptoms who showed no physical signs of heart disease and gave a *history of acute rheumatism.*

2. Running as quickly as possible up 50-70 steps was the exertion used in these tests.

3. The *P-R* interval in two or more beats *before* and the same *after* exertion was measured by a Lucas comparator and the mean taken. The increase in heart rate was reckoned on the electrocardiogram.

4. *The change in electrocardiographic complex as a result of exertion:*

(*a*) *P*, *S*, and *T* were generally increased in amplitude.

(*b*) *R* was slightly reduced in amplitude in some cases.

(*c*) *Q* was often increased, never decreased, in amplitude; in six cases it was only seen in the record after exertion.

TABLE III.

P-R INTERVAL, BEFORE AND IMMEDIATELY AFTER EXERTION; BEFORE AND DURING COURSE OF DIGITALIS.

[Tinct. digitalis, B. P., one drachm daily.]

(Eight patients *with high pulse rate.*)

No.	Initials.	Before digitalis.						After 7 drachms tincture digitalis.						After 14 drachms tincture digitalis.					
		Pulse rate.			*P-R.* interval.			Pulse rate.			*P-R.* interval.			Pulse rate.			*P-R.* interval.		
		Before exertion.	After exertion.	Increase	Before exertion.	After exertion	Change.	Before exertion	After exertion.	Increase	Before exertion.	After exertion.	Change.	Before exertion.	After exertion	Increase	Before exertion.	After exertion.	Change.
1.	J. H. B.	100	170	70	·128	·127	—·001	114	176	62	·145	·124	—·021	106	180	74	·143	·110	—·033
2.	A. E. C.	110	180	70	·155	·147	—·008	116	156	40	·149	·169	+·020	90	172	82	·128	·143	+·015
3.	L. J. W.	120	156	30	·141	·115	—·026	120	166	46	·138	·119	—·019	114	160	46	·138	·113	—·025
4.	H. R. C.	100	174	74	·124	·097	—·027	72	150	78	·132	·105	—·027	132	178	46	·128	·115	—·013
5.	W. I.	90	178	88	·187	·139	—·048	96	154	58	·150	·129	—·021	80	164	84	·236	·136	—·100
6.	S. C. W.	88	136	48	·130	·132	+·002	88	132	44	·134	·124	—·010	88	140	52	·157	·120	—·037
7.	J. K.	104	160	56	·172	·165	—·007	94	142	48	·182	·154	—·028	76	134	58	·185	·155	—·030
8.	H. W.	84	126	42	·143	·122	—·021	76	136	60	·160	·138	—·022	70	120	50	·168	·157	—·011
	Average	100	160	60	·147	·130	—·017	97	151	54	·149	·133	—·016	94	156	62	·160	·131	—·029

NOTE.—Exertion as in Table II, running quickly up 50-70 steps.

those in whom the condition "irritable heart" is severe (as judged from persistently high heart rate) and in whom full courses of digitalis are being administered.

REFERENCES.

[1] LEWIS. *Heart,* 1912-13, IV, 171.

[2] LEWIS AND COTTON. Proc. Physiol. Soc., 1913, p. LX.

[3] TURNBULL. *Heart,* 1910-11, II, 15.

[4] TURNBULL AND MACKENZIE. *Heart,* 1911, II, 292 and 353.

THE OCCURRENCE OF HYPERALGESIA IN THE "IRRITABLE HEART OF SOLDIERS."*

By J. C. MEAKINS and E. B. GUNSON.

(*From the Military Hospital, Hampstead.*)

In the course of the routine examination of a large number of cases of "irritable heart of soldiers" it was observed that in many of these, areas of hyperalgesia existed in the skin of the chest. Further it was noticed that the hyperalgesic areas bore a relationship to the precordial pain so frequently complained of by these patients.

The method used to determine the presence of hyperalgesia was gently to pinch the skin between the thumb and first finger, raising the skin from the subcutaneous tissues and when taut releasing it again. With a little practice the area of hyperalgesia could be mapped out with considerable accuracy. The skin over the anterior surface of the chest was systematically explored by this method. In order that the element of suggestion might be removed as much as possible, the right side of the chest was examined first, then the left side, and finally a comparison of the two sides was made. The points of hyperalgesia were marked and, when the examination was complete, the area of distribution was carefully charted, particular attention being paid to its relation to the intercostal spaces, ribs and bony prominences. The presence of hyperalgesia can be determined, apart from patients' statements, by the change in facial expression and wincing induced when a hyperalgesic area is reached.

Hyperalgesia is often an objective sign of a subjective sensation of pain experienced by the patient when the normal functions of certain organs and tissues of the body are disturbed. Owing to distribution of the hyperalgesia not being limited to the area of skin immediately covering the organ involved, Mackenzie was led to regard the pain as of a referred nature, a conclusion which subsequent observations and experiment have tended to confirm. The mechanism by which referred pain is produced is, in a wide sense, the same in all cases, according to Mackenzie's view. A section of the spinal cord is rendered hypersensitive and stimuli which

* Undertaken on behalf of the Medical Research Committee.

would under normal conditions produce no painful impressions, give rise to a sensation of pain referred to the skin and deeper tissues in the region associated with the organs at fault.

All patients entering one service of the hospital were examined in the above manner for hyperalgesia. Amongst one hundred consecutive cases admitted and complaining of one or more of the symptoms, dyspnœa, palpitation, dizziness or precordial pain, 48 per cent. had hyperalgesia over the left breast in varying degree. All were typical cases of "irritable heart" and no cases presenting signs of organic cardiac disease were included in this series. Some cases gave a history of "pain round the heart" of a fleeting character, such as a stabbing pain on exertion lasting for a few seconds; others complained of a discomfort about the heart of short duration. In none of these cases was hyperalgesia found. On the other hand, patients who complained of recent severe pain, present more or less constantly, nearly always presented an area of hyperalgesia over the left chest in front. Certain of these cases, which gave a recent history of severe pain, but at the time of examination did not complain of pain, presented a definite area of hyperalgesia. This hyperalgesia might persist for a week or even longer after the pain had disappeared.

TABLE I.

69 CASES WITH HISTORY OF PAIN.		31 CASES WITHOUT HISTORY OF PAIN.	
With hyperalgesia	Without hyperalgesia	With hyperalgesia	Without hyperalgesia
48	21	0	31

In 69 out of 100 cases of irritable heart there was a history of precordial pain and in over two-thirds of these cases hyperalgesia was found at the time of examination. The pain these patients complained of was, as a rule, severe; it was nearly always increased by exertion, frequently persisted for days and sometimes prevented sleep. In the cases without hyperalgesia the pain was usually of a fleeting character variously described as stabbing, a stitch, or merely as an uncomfortable sensation.

The relationship between the distribution of the pain and the hyperalgesia was not at all constant. The pain as a rule was confined to a small area. While the zone of hyperalgesia always covered this area it was by no means limited to it. Its distribution was usually more extensive. However, between the severity of the pain and that of the hyperalgesia there was some

relationship. The more severe the pain, the more pronounced was the hyperalgesia and where the pain was complained of there the hyperalgesia was most intense.

TABLE II.

Areas of distribution of hyperalgesia in cases of irritable heart.

No. of cases.	Area involved in hyperalgesia.	Average age of cases.
3	3rd interspace	20 years
7	4th ,,	27 ,,
3	5th ,,	28 ,,
5	6th ,,	27 ,,
1	7th ,,	27 ,,
1	3rd and 4th ,,	41 ,,
4	5th and 6th ,,	25 ,,
9	3rd, 4th and 5th ,,	28 ,,
3	4th, 5th and 6th ,,	25 ,,
1	3rd, 4th, 5th and 6th ,,	24 ,,
1	6th, 7th and 8th ,,	40 ,,
1	4th, 5th, 6th and 7th ,,	29 ,,
4	Left chest	29 ,,
5	Left chest and left arm	26 ,,

The distribution of the hyperalgesia is by no means constant even for areas of the same size in patients who constantly complain of "pain round the heart." In Fig. 1 the distribution of the hyperalgesia in different cases is shown. The large area within the broken line shows the area found in one case, whilst the others, though of smaller size, are situated within this area. The extent of the hyperalgesia varied from a small area an inch and a half in diameter to a very extensive distribution involving the whole of the left side of the chest and neck and extending down the inside of the left arm. Fig. 1 shows the extremes found in these cases. The cases could not be grouped clearly according to the distribution of the hyperalgesia on account of this variation. In five of the cases the extent and severity of the pain and hyperalgesia were identical with that found in cases of serious angina pectoris. If the constancy of distribution in the same patient is tested by repeated examinations, the areas are found to have approximately the same outline from time to time.

The relation between the hyperalgesia described and that of serious angina pectoris is an intimate one. A number of the cases of "irritable heart" have pain, tenderness and hyperalgesia of similar distribution to those found in the grave angina pectoris associated with advanced organic disease. The pain may begin with suddenness and cause the patient great distress. It is most commonly induced by increased exertion in cases of "irritable heart" but it may also occur when the subject is at rest and even during the night. In irritable heart cases and grave heart disease

the pain may have an equally sudden onset and be of equal severity and identical areas of hyperalgesia remain after the pain has disappeared. The following case illustrates these points.

CASE 1. Tpr. H. H. G. Reg. No. 2164, *aet.* 24. Patient was perfectly fit during his training and five months of active service in France. In October, 1915, he developed " influenza." Immediately after this he complained of dyspnœa and palpitation, which were sometimes present when in bed, but were constant on exertion. In December, 1915, he began to have pain around the heart. His condition remained the same up to his admission to this hospital on June the 15th, 1916. He gave no history of rheumatic fever or syphilis. His physical examination was normal ; although he complained of slight precordial pain on exertion there was no hyperalgesia.

On July the 5th, 1916, when out walking he developed a sudden severe pain over the left breast and extending down the inside of the left arm. He was examined shortly afterwards and had hyperalgesia as shown in Fig. 2. This area of hyperalgesia remained for a few days and then gradually disappeared.

The influence of exertion on pain and hyperalgesia.

In patients with " irritable heart " the hyperalgesia most commonly follows or is increased by exertion. In the severe cases the amount of energy expended may be very slight. In fact, in cases which frequently complain of pain and in whom the hyperalgesia is more or less constant the least exertion will render the pain severe. If the amount of exertion which promotes the hyperalgesia be increased, or in some be even maintained, the extent of the hyperalgesia may steadily increase. The following case well illustrates this.

CASE 2. Pte. W. S., 2412, *aet.* 27, complained of palpitation, pain over the heart, choking feeling in throat, breathlessness and giddiness, which he had had for eight years. He did his training with some difficulty at home but when he went to Malta he had to report sick, as he almost fainted when he attempted to undertake the more strenuous training he there experienced.

On July the 24th, 1916, after being in hospital for sixteen weeks, there was a small area of hyperalgesia over the third left intercostal space. On August the 14th, it had extended to the third and fourth spaces, on the 23rd of August it had encroached on the fifth space as well, and by the 29th it covered the second, third, fourth and fifth spaces and extended towards the left axilla and shoulder (Fig. 3).

During this time he had been on mild Swedish exercises, which did not give rise to distress. Between July the 24th and August the 7th, he did these well. Subsequent inquiry revealed the fact that about this time he commenced to take long walks in the afternoon, and he complained mostly of the pain in the evening. When these walks were stopped he was able to accomplish his Swedish drill without pain, and the hyperalgesia gradually diminished until it was as on July the 24th, 1916.

Intercurrent infections and precordial hyperalgesia.

The influence of infections on precordial pain and hyperalgesia is very striking. We have had a number of cases of " irritable heart " in whom the chief complaint during the onset and course of some intercurrent infection was precordial pain. The following cases will illustrate this.

CASE 3. Lance-Corpl. H. W. G. Reg. No. 162, *aet.* 20. Patient was perfectly fit until August the 8th, 1916, although he had been wounded twice. On this date he was slightly " gassed." During the next few days he gradually developed shortness of breath and pain around the heart which compelled him to report sick. He was admitted to this hospital on October the 27th, 1916. On examination, nothing abnormal was found except a small area of hyperalgesia over the fourth and fifth intercostal spaces in the nipple line.

On the morning of October the 31st, 1916, he complained of severe precordial pain. On examination there was pronounced hyperalgesia over the fourth and fifth left intercostal spaces. This was so acute that the pressure of the bed-clothes was uncomfortable. The hyperalgesia was much more extensive than on the previous examination (Fig. 4) and he experienced difficulty in taking a deep breath on account of the pain in the left side. During the day his temperature rose to 102 degrees F.. The next morning he was better, the temperature was normal, the hyperalgesia had disappeared and the tenderness was less acute, but the area of hyperalgesia remained unchanged. During the day the temperature was again elevated and the pain was more severe. No definite cause of the fever could be found. By November the 4th, 1916, he had no temperature, the pain and hyperasthesia did not return, but the area of hyperalgesia remained unchanged. During the ensuing week, however, it gradually diminished until it was as on admission. At no time was there any abnormal signs in the heart or the left lung and pleura.

CASE 4. F. M. Reg. No. 19522, *aet.* 22. He was quite well up to September, 1915, when he was " gassed " ; following upon this he had pain in the left chest, dyspnœa and palpitation on exertion which was so severe as to incapacitate him for duty. When examined on April the 1st, 1916, there was an extensive area of hyperalgesia over the left chest and axilla with numbness down the inside of the left arm to the elbow. No abnormal signs were noticed in the lungs at this time. During the next few weeks he complained frequently of the pain in the left chest. During the first week in May he had an occasional evening temperature of 100° to 101° F. and a few night sweats. He lost ten pounds in weight between April the 23rd and May the 7th. After repeated examinations of the lungs during this period there was no doubt that he was suffering from an acute infective process at the apex of the right lung, as evidenced by his general condition and the physical signs which were :—harsh breath sounds, prolonged expiration with fine crepitant rates at the right apex. During this time the precordial hyperalgesia had gradually increased in area until the whole of the left chest in front, the left side of the neck, the left axilla and the inner side of the left arm were affected as shown in Fig. 5. The increase in the area of hyperalgesia could be traced practically from day to day.

Etiology of " irritable heart " and precordial hyperalgesia.

An analysis of the histories of the cases of " irritable heart " presenting hyperalgesia was made to determine so far as possible the etiology of the condition (Table III).

TABLE III.

48 *cases of " irritable heart " with hyperalgesia.*

No. of cases.	*Etiological factor.*
15	Rheumatic fever
1	Physical strain
7	Shell-shock and gassing
1	Syphilis
18	Recent examthemata, and other infectious diseases
6	Unknown

The large percentage of cases which have suffered from infectious diseases, especially rheumatic fever, amongst those suffering from " irritable heart " with precordial hyperalgesia, suggests that there is some connection between these infections and the symptoms. This is further emphasised by the

close relationship of the increase of the precordial hyperalgesia to the acute manifestations of the infectious process.

After the infectious processes the next most common etiological factor is shell-shock. The relatively small number of these cases coming under our observation may be explained by the fact that shell-shock is treated as such ; thus unless the symptoms of "irritable heart" are very pronounced these cases would not come under our observation. If all cases suffering from these conditions and symptoms of "irritable heart" were systematically examined for precordial hyperalgesia it would be found quite frequently. One of us has had an opportunity of doing this at the Canadian Red Cross Special Hospital at Buxton. In fifteen cases of shell-shock having symptoms of "irritable heart" fifty per cent. had precordial hyperalgesia.

Severe exertion alone seems to play a very minor role in the etiology of irritable heart. That exertion may increase the symptoms, particularly if it is undertaken shortly after an acute infection, is certain and many examples illustrating this might be quoted. In fact, it is usually during the convalescence from an acute infection, when the patient is walking, that the precordial pain is first noticed. But severe exertion by itself is very rarely a first cause of precordial pain and the other symptoms of "irritable heart." We have had only one such case under our observation.

Relation of precordial hyperalgesia to the capacity of the patient for exertion.

All the patients suffering from "irritable heart" who were examined for hyperalgesia were placed on physical drill, this at first being limited to easy exercises. Later the exercises were advanced in severity as the condition of the patients warranted.

In Tables IV and V the results are tabulated. It will be seen that all cases do not react equally. It must be borne in mind that the hyperalgesia was only one of several severe symptoms which rendered it necessary to remove a patient from exercises. Also, some patients when they began the mildest exercises had hyperalgesia which shortly afterwards disappeared. This was particularly evident in *CASE* 8 (*vide infra*).

It will be seen from Table IV that the presence of precordial hyperalgesia is significant of slow subsequent progress upon graded exercises. Eighty-one per cent. of the cases with hyperalgesia were unable to advance beyond the simplest exercises ; while in the case of the more severe exercises it was found

TABLE IV.

Cases of "irritable heart" with hyperalgesia.

No. of cases.	Exercise on which material symptoms appeared.	Mild hyper-algesia.	Moderate hyper-algesia.	Severe hyper-algesia.
24	A. 15*	8	10	6
7	B. 15	2	3	2
2	C. 15	2	0	0
6	A B 30	2	2	2
4	B.C. 30	3	1	0
2	C. 30	1	1	0
1	D. 30	1	0	0
1	Route march	1	0	0
1	Completed exercises without symptoms	0	1	0
48		20	18	10

that the patients with hyperalgesia who could accomplish them were very few. Only one or two patients with hyperalgesia were able to carry out the most severe exercises at all.

TABLE V.

Cases of "irritable heart" without hyperalgesia.

No. of cases.	*Exercise on which material symptoms appeared.*
7	A. 15
3	B. 15
2	C. 15
6	AB. 30
4	BC. 30
1	C. 30
6	D. 30
4	Route marches
19	Completed exercises without symptoms
52	

* The letter refers to the grade of exercise, the number to its duration in minutes. (See Brit. Med. Journ., Sept. 23rd, 1916.)

On the other hand the majority of the cases without precordial hyperalgesia progressed far. Thirty-six per cent. of our series accomplished all the exercises, even to route marches, without material symptoms (Table V).

In several cases hyperalgesia was found in other regions, particularly the abdomen. The association of hyperalgesia of the left chest with hyperalgesia in other areas is of special interest. The following cases are cited in some detail to illustrate the association of the precordial hyperalgesia with the hyperalgesia of lesions elsewhere in the body.

CASE 7. Pte. A. J. Reg. No. 1600, *aet.* 25. He contracted dysentery in Gallipoli in September, 1915. During his convalescence he developed dyspnœa and pain in the left chest below the nipple. These symptoms persisted until he was examined on May the 1st, 1916. They were increased by exertion. There was a moderate area of precordial hyperalgesia and extensive abdominal tenderness with bands of hyperalgesia in both flanks, as shown in Fig. 6. Shortly after this he had a short attack of diarrhœa with an aggravation in the intensity of the tenderness and hyperalgesia, but no increase in the distribution of either. An examination of his fæces at this time revealed the presence of the cysts of amœba histolica. By the middle of June he was entirely free from all areas of tenderness and hyperalgesia and was able to accomplish considerable physical exertion without symptoms. The hyperalgesic areas disappeared simultaneously from chest and abdomen.

CASE 8. Sergt. G. G. Reg. No. 15548, *aet.* 38. In 1900, when serving in South Africa, he had a severe attack of dysentery. During his convalescence he suffered from dyspnœa and palpitation which lasted for some months. In civil life he had not been troubled by these symptoms, but as soon as he joined the army they returned in slight degree; but they were not sufficient to prevent his performing his full duty. At Suvla Bay, in November, 1915, he had another attack of dysentery and immediately afterwards the dyspnœa and palpitation became very troublesome and were associated with pain about the heart. His condition gradually became worse and eventually the least exertion greatly accentuated the pain and produced a sensation of numbness in the left forearm and hand. On April the 12th, 1916, there was hyperalgesia in the fourth and fifth left intercostal spaces, in addition there was numbness over the inside of the left forearm below the elbow, and over the whole hand (Fig. 6); and there were also bands of hyperalgesia in both flanks following almost the same distribution as was observed in the preceding case; but there was no tenderness on deep pressure. This patient was under observation for a considerable time and the close resemblance of the distribution and character of the pain and hyperalgesia to those found in angina pectoris was striking.

The frequent occurrence of the symptoms of "irritable heart" after dysentery has already been pointed out by one of us. That there was originally a connection in both the cases now cited between the abdominal condition and the symptoms of "irritable heart" is strongly suggested by their histories. In the first the symptoms were evidenced directly the patient attempted to exert himself, they appeared to be maintained by the persistent infection of the bowel. In the second case the symptoms followed two different attacks of dysentery separated by an interval of fifteen years; and in the second case the abdominal condition seemed more acute while the sense of precordial oppression was severe. The first man steadily improved until he was fit to return to duty; the second did not improve. A number of other cases of abdominal and precordial hyperalgesia, of which the following are examples, came under our observation.

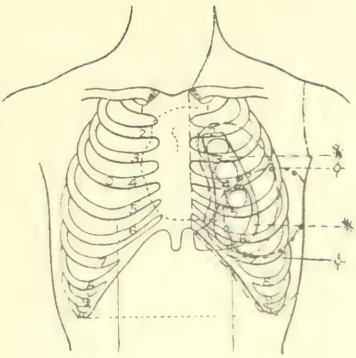


Fig. 1.

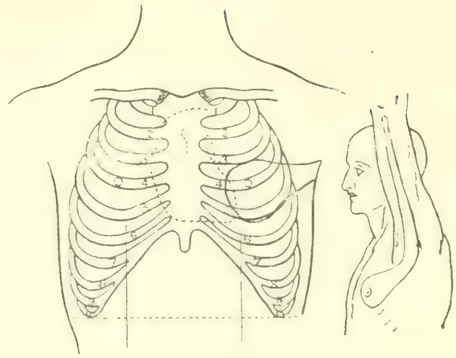


Fig 2.

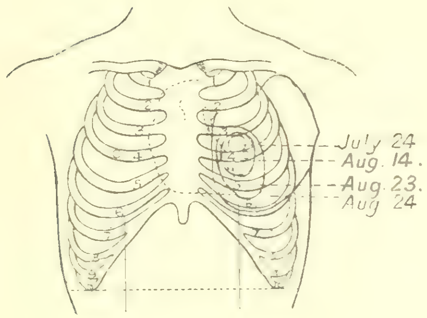


Fig. 3.

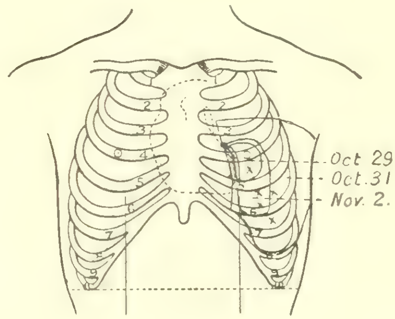


Fig. 4.

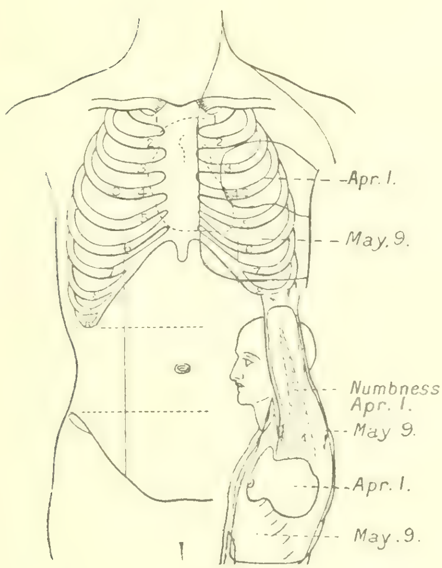


Fig. 5

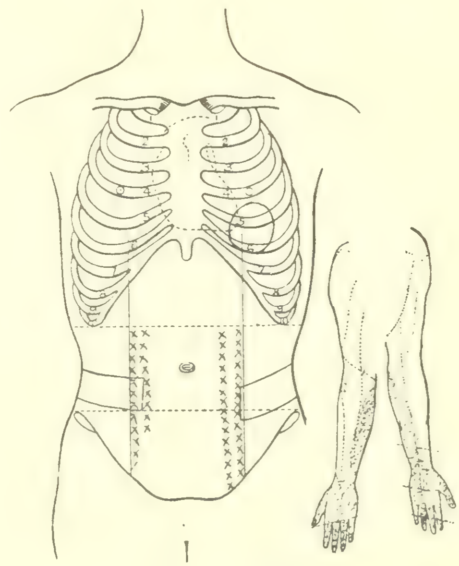


Fig. 6.

CASE 9. Pte. R. J. G. Reg. No. 20065, *aet.* 25. Patient had had shortness of breath, palpitation and pain " about the heart " for the past five years, which symptoms were first noticed after an attack of acute appendicitis; since that time he had had several more attacks. When he joined the army in November, 1915, he was free from all symptoms, but six weeks later the dyspnœa, palpitation and pain " about the heart " returned. On April the 1st, 1916, he had an acute attack of appendicitis. There was precordial hyperalgesia over the fourth, fifth and sixth spaces in the nipple line and also a band of hyperalgesia in the right flank with maximum intensity over McBurney's point where there was also conspicuous tenderness (Fig. 7). An operation was performed on April the 3rd, 1916. An acutely inflamed appendix was found and removed, and the patient made an uninterrupted recovery. On May the 3rd, 1916, the abdominal hyperalgesia had disappeared, and there was remaining only the small area in the fifth left intercostal space as shown in Fig. 7.

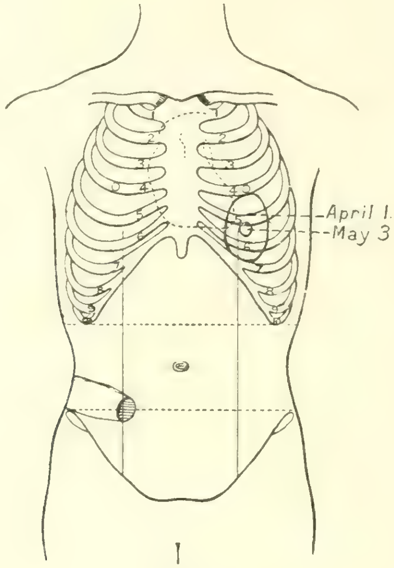


Fig. 7.

CASE 10. Pte. H. E. B. Reg. No. 76164, *aet.* 22. He enlisted in October, 1915, and performed his duties without trouble until March, 1916, when he developed abdominal pain. This was not enough to interfere with his work, but gradually he began to suffer from shortness of breath, palpitation and pain in the left breast. These symptoms became so troublesome that he reported sick and entered the hospital on April the 6th, 1916. At this time there were no abnormal signs except hyperalgesia over the third, fourth, fifth and sixth left intercostal spaces from the midsternal line to the axillary line. There was also hyperalgesia in the epigastrium and right lower abdominal quadrant. There was no change in the condition under observation and finally he was operated upon on May the 5th, 1916, for chronic appendicitis. The appendix was found to be chronically inflamed and adherent to the surrounding structures. It was removed and the patient made an uninterrupted recovery. On May the 30th, 1916, all the precordial and abdominal hyperalgesia and tenderness had completely disappeared.

In both these cases there seemed to be close relation between the onset of the attacks of appendicitis and the symptoms of " irritable heart." This is further emphasised by the almost complete disappearance of the precordial hyperalgesia in the first case and its complete disappearance in the second after removal of the inflamed appendix.

At present it is difficult to explain the direct cause of precordial hyperalgesia. It is not dependent upon altered rhythm or heart rate, as patients who have a marked arrhythmia or tachycardia are sometimes entirely free from pain and hyperalgesia even on exertion. At other times and not infrequently at rest, when the pulse is comparatively regular and slow, they may suffer from severe pain associated with an extreme degree of hyperalgesia. Also there is no proof that the hyperalgesia is dependent upon an organic lesion of the heart, as it occurs more often in cases without than in those with signs of organic cardiac disease.

That causes so widely separated as an acute infection, shell-shock, and gas poisoning can, and do, produce identical symptoms in patients who present no demonstrable sign of organic disease, suggests the intervention of an "unknown factor" in the production not only of the precordial pain and hyperalgesia, but also of other symptoms of "irritable heart."

Summary and Conclusions.

1. Irritable heart cases who complain of recent severe precordial pain nearly always present an area of hyperalgesia over the left chest in front.

2. The hyperalgesia observed in many of these cases and the hyperalgesia present in cases of grave angina pectoris are very similar. The distribution of the hyperalgesia, the factors provoking it, are also strikingly alike in the two conditions. Exertion generally increases the hyperalgesia.

3. Infections exercise a striking influence on precordial pain and hyperalgesia. These latter are more marked during the progress of an infectious disease, sometimes dating from it.

4. The presence of precordial hyperalgesia in irritable heart cases is significant of slow subsequent progress upon graded exercises. Eighty per cent. of the cases with hyperalgesia cannot undertake more than the simplest exercises ; on the other hand, of the cases without hyperalgesia more than thirty per cent. advance to route marches without experiencing untoward symptoms.